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PLANT PRODUCTION CONTROL

PLANT
PRODUCTION
CONTROL

CHARLES A. KOEPKE

Production Management Consultant
Industrial Engineer

Second Edition

JOHN WILEY & SONS, INC., NEW YORK
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CHARLES A. KOEPKE

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PREFACE

The reception of the first edition of this book has been gratifying. In my opinion, it shows that the trend of textbooks for industrial engineering is continuing toward the specific rather than the general. Several decades ago most of the industrial engineering books were quite general in that they tended to discuss in one book practically all the various subdivisions.

At present there are few or no general books on mechanical, electrical, or civil engineering. These professions have grown to such proportions that a series of highly specialized books is necessary for complete coverage of all the branches. This policy is also becoming more desirable for industrial engineers because of the increased responsibilities and opportunities offered to them in modern industry.

The second edition is an outgrowth of an extensive consulting practice in many types of industries. A number of changes and additions have been made to incorporate the current practices for controlling production.

For the best control it is necessary to have accurate and current data for all parts and materials at all times from the engineering or specification departments. Many industries, both large and small, have had difficulty in getting completely reliable and timely information from their design engineering departments during the postwar period. The need for accurate and reliable information must be constantly placed before the design engineers.

Throughout this revised edition, the various interrelationships between the several line and staff groups are pointed out and discussed. Under good control procedures no one group should be allowed to dominate. Coordination and team work should be the driving force to get the complicated problems of modern industry under control.

The questions and problems for the various chapters have been selected to provoke discussion. Some of the problems have more data presented than are actually needed for their solution. This of course is similar to the actual pattern in industry. No one will present the young engineer with the exact data needed. He must be able to look over the field, select the data *he needs*, and begin the solution of the problem. It probably is better to let him select his data and make his assumptions and possible mistakes under the guidance of an able

teacher than it is for him to learn the hard way, under an exacting industrial executive.

Suggestions, additional problems, and thought-provoking questions will be greatly appreciated.

C. A. KOEPKE

St. Paul, Minnesota
March 1949

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CHAPTER I

INTRODUCTION

BACKGROUND FOR PRODUCTION

World Industrialization. The development of industry in the nations of the world is steadily progressing. During each decade the manufacturing techniques and facilities of established factories have improved in progressive nations. Moreover, new sections of the United States and certain nations, formerly considered backward industrially, are developing important industrial potentials.

On the other hand, there are some nations and peoples who are still in the early stages of industrial development. We are apt to speak of the Stone Age or the domestic system¹ of manufacture as though they were things of the distant past. Actually, however, there are places on the globe where these primitive conditions exist. Arctic explorers, such as Stefansson, report tribes of Eskimos who still have implements of stone and bone. Necessarily, these tools indicate that these people are still living in a primitive state.

Domestic System Still Prevalent in Old Mexico. The art and science of manufacturing has grown tremendously since the domestic system of producing goods was developed over 200 years ago in England; yet a study by the author of industry and handicrafts in Mexico shows that, with the exception of the modern industries in the large cities such as Monterrey, Mexico City, Puebla, and Guadalajara, the domestic system is largely used to produce goods for the Mexican people. An entire village is dedicated to a particular handicraft. A village with a few score to several hundred people makes baskets, while another makes pottery. At least one community is still using the forerunner of all lathes, the primitive bow lathe, to produce exquisitely turned articles from wood.

Early Factories and Their Regulation. England was the first nation to discard feudalism and gradually adopt methods of manufacturing

¹ A method of producing goods in the worker's home with the aid of tools owned by the worker.

which evolved through the domestic system as it developed until the factory system² as we now know it began to emerge.

In 1340 Thomas Blanket, one of three Flemish brothers who were promoting the making of cloth in Bristol, was ordered by a local court to pay a fine "for having caused various machines for weaving and making woolen clothe to be set up in his houses, and for having hired weavers and other workmen for this purpose."³ From this assembling of machines and hiring of workers to operate them, we may assume that the first factory was tried more than 400 years before the factory system was fully developed and accepted as necessary in England. In the later part of the fifteenth century several capitalists such as John Winchcombe, known as Jack of Newbury, and Martin Brian of Manchester had large forces of people working in textile factories. Jack of Newbury was reported to have employed over 1,000 persons in his large factories.

The growth of such factories was halted, however, by an act of the English Parliament which read in part:

. . . wealthy clothiers do in many ways oppress them by setting up and keeping in their houses divers looms, and keeping and maintaining them by journeymen and persons unskilled, to the decay of a great number of artificers . . . ordained and enacted by authority of this parliament that no person . . . shall keep, or retain, or have in his or their houses or possession, any more than one woolen loom at a time.

This action was taken to prevent the textile industry from falling into the hands of large capitalists. Later, weavers living in towns were allowed two looms each.

Here and there factories with power furnished by water were set up to drive the simple machines used before the Industrial Revolution. A silk mill at Derby was the first English factory in the modern sense. It is described in Taylor's *Modern Factory System* as containing "26,586 wheels and 97,746 movements, which work 73,726 yards of organizine silk thread every time the water wheel goes around, being thrice in one minute; and 318,504,960 yards in one day and night." This clearly was something entirely different from Jack of Newbury's factory where all the machines were run by manual power. Both animal and water power were used to drive the simple machines in

² A method of production under which workers are congregated in a central place and make goods with tools owned by the factory.

³ *Modern Factory System*, R. W. Cooke-Taylor, Kegan Paul, Trench, Trübner and Co., Ltd., 1891.

use before the Industrial Revolution. The machines were the same as they had been for many years, but man had been freed in some places from furnishing the manual power to turn them.

Domestic System Fails to Supply the Demand. Up to about 1760 the old order of manufacturing had not been disturbed very much. However, the domestic system was becoming inadequate to meet the ever-increasing demand for goods. The fundamental manufacturing processes were all performed by the labor of human hands. In some instances animal and water power had been used to drive these simple machines, but for the most part the power was supplied by the operator. The simple machinery was cheap so that each workman could afford to own it, but its operation required skilled hands. The worker was the supreme element in the manufacturing process and the machine was an adjunct to him. This simple combination of man and machine had certain advantages, particularly for the workman, but it could not produce goods fast enough to satisfy the demands of England's commerce.

The Industrial Revolution. Authorities differ on what caused the Industrial Revolution: some say the invention of the great textile machines and the steam rotative engine was responsible; others claim a new method of thinking had evolved which was climaxed by Adam Smith's *Wealth of Nations*; still others point to the new commercial expansion which was demanding more goods than the old system could produce; and some feel that the rise of capitalism was largely responsible. Undoubtedly, capitalism at least provided the driving force behind the changes. The inventions resulted from economic necessity. They were asked for by the industrialists and government alike.

Need for Prime Movers. While the Industrial Revolution was not caused by the use of power machines, steam engines were developed at about the same time because animal and water power were soon found to be inadequate for the new textile machines.

When Newcomen built his engines, he devised them so as to utilize the known skills of available workmen, the materials at hand, and current methods of production. On the other hand, Watt's improvements were in fundamental design. It was necessary for him to design better cylinders, pistons, and bearings. He could not limit himself to the known skills, materials, or methods. Before Watt began his experiments, there were no steam engine factories, no machine tools worthy of the name, and little fundamental or applied science that could be used as a basis for design, and certainly no organization for accomplishing any of this.

Need for a Science of Thermodynamics and Design. Mechanical engineering as a profession was practically unknown before James Watt began his improvements in steam engine design. The science of thermodynamics was still to be developed, and, consequently, mistakes were made in the fundamental design of the engines. Watt and others associated with him would get ideas for improvements, but, since there was no way to calculate their effect, the only way to test the idea was to try it.

Development of Machine Tools. Only a few machine tools existed when Watt built his first engines. Cylinders were made from cast iron lined with wood which in turn was lined with tin or copper hammered to shape. Pistons were made from wood covered with wool, canvas duck, or paper lubricated with tallow and kept moist with cow dung. The sheet metal liners became unsoldered and enough air leaked in to spoil the vacuum. The steam pressure, which was only a few inches of mercury, caused the liners to bend and these in turn loosened the solder.

With new experience, Watt and his associates designed more machine tools requiring more skilled operators. The acute shortage of skilled men retarded the expansion rate of the engine factories. It is interesting to note, however, that specialization of skills was not practiced. Millwrights, molders, patternmakers, fitters, machinists, and blacksmiths were usually capable of doing each other's work. Actually, all the skilled workmen did their jobs by hand, and no shop division of duties had yet been made.

Just as today we are able to measure more accurately than we can machine commercially, we find that this condition also existed in 1772 when Watt made the first micrometer. He states, "It divides distinctly an inch into 400 equal parts." Later he said that the instrument was not in error more than $\frac{1}{200}$ of an inch in 9 inches.

The first boring machines were weak, unreliable mechanisms in which the tool was advanced by hand. When we realize that some of these early cylinders were from 24 to over 60 inches in diameter and up to 9 feet long, it is easy to understand their machining difficulties. In the first place the cylinder walls were only from 1 to $1\frac{1}{2}$ inches thick. The cupolas of that time could melt only limited quantities of iron. If the castings were large, they had to have thin sections. The problems of holding such a large weak casting for machining were quite difficult. Any undue clamping force would allow the castings to spring out of round when the clamps were removed.

Machining of Flat Surfaces. The machining of flat surfaces was the hardest problem for the early machine tool designer. Even after the

first cylinders were bored the end flanges were still left as rough castings to be chipped and filed to as flat a finish as possible. Cements were used to fill the cavities too deep to be chipped or filed out. In 1782 the machine shop complained to the foundry as follows:

We beg that particular attention may be paid to casting the flanges straight; we have much reason to complain of this part, hitherto, . . . we have been obliged to chisel out the iron to the proper cone, this expense may be saved by some attention paid in the casting.

As late as 1802 the entire machine shop at Soho did not contain a planer or other machine for producing flat surfaces. The machines however included eight metal-cutting lathes, three drill presses, one wood lathe, and one lapping machine.

In the early machines, during the entire boring time of a cylinder the tool had to be fed by hand. In 1802 James Watt, Jr., wrote concerning a new type of boring mill, "His cutter block is pushed forward upon the boring bar by an endless screw, which, or some similar contrivance, we mean to adopt, both to guard against the negligence of the borer and to save part of his wages." Thus we see that improvement of method to reduce labor costs was also in vogue in 1802.

Lack of Tolerances, Quality, and Specialization Caused Manufacturing Troubles. All the cylinders for Watt's engines were bored in outside plants. Customers shopped around to get the parts as reasonably as possible. Some engines were faulty owing to poor workmanship and poor fitting of parts which came from several sources. In desperation Watt wrote⁴ to a machine shop complaining of their poor cylinders and boasting of the high degree of accuracy he was obtaining from Wilkinson in 1776.

Wilkinson hath bored us several cylinders almost without error that of 50 inches diameter for Bentley and Co. doth not err the thickness of an old shilling in no part so that you must improve in boring or we must furnish the cylinder.

Even the difference between an old and new shilling would be too indefinite to be of any use today in discussing measurements.

There were no specialized manufacturers of such things as screws. The Soho company made its own screws and received inquiry from a rival engine company concerning the cost of an order of screws. Again the question of price arose as shown in this excerpt:

⁴ *Iron and Steel in the Industrial Revolution*, T. S. Ashton, Manchester University Press, 1924, p. 64.

Our screws are made with solid heads [i.e., not welded on] and they are screwed in stocks and dies with square topt threads like a vicepin and afterwards brought all to one size by a screw plate. The nuts and burrs are first entered by a taper tapp and finished by a tapp which goes quite through them and makes them equally wide upon both sides. Such screws we find vastly preferable to the common sort. . . . after all that pains in making them we cannot sell them under 6d. per lb., and hitherto have been losers by selling them at that price.

Although it was the custom to make the various units of an engine in three or four places, there were no tolerances stated on any of the drawings. Watt wrote to one of his outlying plants, "The water pump bucket to be the same as Mr. Colevilles, you will please to be particularly careful in boring piston to dimensions. . . . I say nothing about quality or time, you know we are all upon honour." With all due regard to being upon one's honor it was still very difficult to produce accurately fitted parts. When we consider the crude machinery, the lack of consistent or accurate measuring standards in the various plants producing the parts, and the rather poor raw materials, it is surprising that engines could be assembled at all.

The engines actually did give a good deal of trouble owing to defective workmanship. There are a number of published letters concerning trouble incurred in operating. One, from a Nottingham cotton mill owner, written in 1793, complained of both bad workmanship and poor material.

The wheels of the sun planet motion were so bad that they were replaced with new ones; the connecting-rod top had broken; the coupling-link and the connecting rod gudgeons had broken and had to be replaced; the fastenings for the gland of the piston rod stuffing box had broken; the top and bottom exhaust spindles were made of bad iron and they had broken; the racks and sectors for the valves were badly fitted and very much out of order . . . and many other matters.

All these misfits and poor material occurred in an engine that had been in service only a year.

Transportation in Watt's Time, Materials Handling. Considering the undeveloped state of transportation in Watt's time, it must have been a real problem to transport the various engine parts from widely separated sources to the point where the engine was to be erected. It is clear that much forethought and an extensive organization were necessary, and that the commercial side of the Boulton and Watt concern had many difficulties to surmount. Goods made in London

could be carted to the docks and shipped by water to one of the Cornish ports, but from Soho or Birmingham goods had to be carted to the canal and then by boat to the rivers. Piston rods made at Seaton were usually shipped at Whitehaven to Liverpool and were then taken to Chester where they were loaded on the same boat as the cylinder shipped direct from Bersham. The main difficulty was the absence of materials handling equipment for heavy goods. Cylinders had to be rolled in and out of the ship's hold. Often the hatchways were too small for the engine parts and another ship would have to be engaged.

Some parts were sent to their destination by wagons. In 1791 John Wilkinson's clerk at Bersham wrote:

The last cylinder which went to Ocker Hill was taken by our team, and thrown over in a field near where it was erected. The same might be done with this . . . there is no danger in throwing a cylinder from a wagon on soft earth, but it is not so at Preston Brook. I would sooner trust to throwing it off the wagon there than to their cranes.

It appears that the general practice was to throw the wagon over with the cylinder on it.

Damage in transportation was quite common. One piston rod was ruined beyond repair by being shipped along with some lime which became wet during the trip.

Investment per Employee in Early Metal-Working Plants. An inventory of the Soho plant in 1786 showed the value of the property to be £2,319 with about seventeen men employed. In 1800 this value had increased to £9,010 and the employees to fifty-two. The investment per employee was about £136 in 1786 and had increased to £173 in 1800. Thus it can be seen that very early there was a tendency to increase the value of the facilities made available for each workman. Today the Ford Motor Company declares that they have about \$9,000 invested in facilities for every workman on the payroll, or, roughly, thirteen times as much as was invested per man in 1786 in the Soho engine works. The American Rolling Mill Company states that \$8,643 per mill employee is required. The over-all figure for American industry⁵ is about \$6,500 at present compared with \$3,200 in 1914 and \$1,900 in 1899. Certain nonmanufacturing industries have even higher investments per wage earner. The electric utilities have \$47,000 and the railroad industry \$26,000 average investment per employee.

⁵ Investment figures furnished by National Association of Manufacturers.

The Evolution of the Mechanical Engineer. The engines briefly discussed in this chapter were made less than 200 years ago. They were crude, unreliable mechanisms, expensive to run, and difficult to maintain in good order. The problems involved in their manufacture were of a pioneering nature. There was little precedent and no traditional approach to most of the things which had to be done. The patience and genius of the men of that time may be appreciated when we realize the facilities with which they worked. From these events came some of the beginnings of modern specialization.

The mechanical engineer began to evolve during the early development of the steam engine because the technical problems in the design of the engines and machine tools grew beyond the scope of the ordinary mechanic. The mechanic had his own problems of learning the techniques brought about by the newly developed machine tools and foundry requirements. Moreover, since there was no manufacturing background to depend on, the mechanic was wholly absorbed with developing a manufacturing method. It is no wonder then that another group had to develop a science to predict performance and to design better machines. This latter group developed into mechanical engineers, and until the close of the nineteenth century they were interested primarily in machine design. The methods used in producing the machines and the flow of materials through the plant were left to the foremen and mechanics.

The typical factory organization during the early expansion of American industry and up to the time of Frederick W. Taylor consisted of general manager, superintendent, foreman, and workmen supplemented by timekeepers and storekeepers. This line organization was the outgrowth of a rather easy-going method of manufacturing in which the mechanic was the key man. Generally speaking, the foreman and superintendents were promoted mechanics who retained to a large degree the mechanic's viewpoint and background.

Shop orders in these early unsystematized shops were recorded in a simple manner or even given verbally by the sales department to the superintendent. The superintendent told the details, such as promised delivery date, manufacturing procedure, and proper materials, to the foreman who in turn transmitted the outline of information to the workmen. It was assumed that the superintendent knew his business and that the several foremen knew theirs. The workmen were expected to sense by their trade knowledge what was wanted and to ask questions when they were not sure.

The foreman, along with the mechanic, carried the load of getting the work done properly. The foreman gave out work to each work-

man when the previous job was completed. He and the mechanic had to be sure that material was at the work place for the new job, that tools of the proper kind were available, properly sharpened, and ready for use at the machine, that the work was done in the cheapest and best way, and, finally, that the work passed inspection. If any questions arose that could not be answered by the mechanic or foreman, the information was sought from the superintendent or from the manager. In the meantime the job was held up pending solution of the difficulty.

The shop of any size relied on a group of stock chasers to trace the parts and to find the reasons for delays. The delays generally were caused by a series of bottlenecks in the shop which jammed worse when the pressure was on. To keep production going, more stock chasers were hired because it was thought too costly and impractical to do it in any other way.

The Industrial Engineer. It was logical, when Frederick W. Taylor and others found these conditions widespread in many industries, that something had to be done if manufacturing was to continue its development. Here again a further division of labor was indicated. That is, another group of specialists, largely mechanical and industrial engineers, found it necessary to develop a science of planning for manufacturing just as, about 100 years earlier, it was necessary to develop a science of design. In each case the manufacturing problems had developed to such an extent that the ordinary mechanic could no longer cope with all the combinations of art and science necessary to deliver the goods on time. The engineer and mechanic had been a wonderful team throughout the nineteenth century, and billions of dollars' worth of products had resulted from the fine co-operation between them. However, as machines became more complex and production schedules became larger, more complex, and more rigid, it was impossible to continue under the old plan.

This chapter's very brief review of industrial development points out the extent of the world's progress in the production of goods. The improvement has been along many lines, including, among other things, design, materials, machines, personnel policies, and industrial organization. Some persons, not realizing the great advances made since the Industrial Revolution, become impatient because industry is still imperfect. Except for occasional short periods, there has been steady progress in the production of a greater variety, quantity, and quality of goods. Better methods of production, lower costs, better labor relations, and higher wages have all contributed to this progress.

This development will undoubtedly continue, but past performance also indicates a gradual process of evolution.

Engineers and production executives learn by mistakes and successes. The serious student of industrial engineering can also learn by the mistakes and successes of those who have preceded him. A study of both industrial history and current literature dealing with factory problems will give the student a better background for his future actions.

Many different management philosophies have been and are being tried. Some have been abandoned; others are still in the process of development. This constant research for an ideal pattern of industrial behavior and a better management technique has been made by many persons in all types of industry located in many countries. The bibliography at the end of this chapter suggests sound reading for further study.

QUESTIONS FOR DISCUSSION

Collateral reading is necessary to discuss these properly.

1. What factors have caused Mexico's industrial development to lag behind that of its large northern neighbor?
2. Why was the domestic system a natural step in the growth of England's industry?
3. Why were England's early factories resented by the people?
4. What factors caused a major change in English industry about 1760?
5. Was obsolescence or depreciation the greater menace in the early development of the textile industry?
6. Which came first, the Industrial Revolution or the new prime movers?
7. Discuss the evolution of mechanical engineering during James Watt's time.
8. Was the evolution of the mechanical engineer a natural or a forced development?
9. How did the lack of skilled workmen and machine tools affect the design of Watt's first engines?
10. Why were machines for producing flat surfaces not available as early as lathes and drill presses?
11. What factors prevented the production of accurate engine cylinders?
12. Why did Watt discourage the building and use of rotative engines?
13. Discuss the lack of tolerances in the production of Watt's engines.
14. Discuss the typical factory organization during the early expansion of English and American industries. Do any industries in America use the same plan today?
15. What caused the American colonies, with all their raw materials, to be rather slow in developing industry in America?

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CHAPTER II

AN ANALYSIS OF SOME PRODUCTION FACTORS

This chapter is concerned with a simple analysis of the development of some of the potent factors which have made great production possible.

These factors are presented as a rough guide to aid the industrial engineer in selecting the areas of activity which can be more profitably developed. Some of these factors have advanced to a high degree and probably any future improvement will require extensive work. On the other hand, some of these factors, which are important for modern production, are only partially developed. Further expansion of this latter group should show good returns, and industrial engineers, as a part of their contribution to production, should help develop them to their maximum usefulness.

CUTTING TOOL MATERIALS

The story of cutting tool materials is intimately connected with modern production. The speed with which metals and other materials of construction can be machined has an important bearing on production cost, not only in the metal-working industry but also to some extent in practically all industries. Even if no actual cutting or shearing operations are done in a particular industry, there usually must be some equipment or machinery in the shop or office which is made by cutting tools. Industry depends on modern tools; costs would be higher if we had to depend on the cutting materials of only a few decades ago.

During the unknown thousands of years when man was in the Stone Ages, no goods were produced. Mere existence was precarious, and progress was so slow that over periods of many centuries it could scarcely be noticed. Although the use of bronze for cutting tools, which began about 2000 B.C., was a noticeable improvement over the stone tools, it still did not have any great effect on the production of useful articles. Bronze was used to make the common knifelike tools and axes, but it was of little value for production. The use of

iron for utilitarian things such as nails, hinges, and cast cannon long preceded its use as the basic material for carbon tool steel.

Carbon Tool Steel. By using a slow process of carburization in a charcoal fire, reducing the section by drawing, folding the drawn-out section, and welding the fold and repeating the process over and over, the artisan did create some wondrous swords of which many fabulous tales are told. These thin, laminated sections of carburized steel were actually carbon tool steel. But not until about 1750 was the iron industry able to produce carbon tool steel cheap enough and in large enough quantities to be useful as a cutting tool for industry. Carbon tool steel could be hardened and tempered to cut any of the metals then in common use. In fact, carbon tool steel was the supreme cutting tool material until the close of the nineteenth century when "mushet" steel, which was an improvement over the carbon variety, was introduced.

High-Speed Steel. When Frederick W. Taylor¹ and his associates were experimenting with metal cutting they developed high-speed steel capable of cutting with about twice the speed of carbon tool steel. This discovery had far-reaching results. Practically all machine tools had to be redesigned to take the added strain the higher cutting speeds entailed. Production per man increased and the cost of manufactured articles started downward.

Stellite. In 1914 Elwood Haynes of the Haynes Automobile Company announced a new cutting tool material called Stellite. When used on certain materials, notably cast iron, Stellite was able to double the cutting speed over that obtained with high-speed steel. This new material contained little or no iron and again the metallic base for cutting tools was changed—this time from iron to tungsten and chromium. Stellite ruled supreme in its field until 1928 when tungsten carbide was announced.

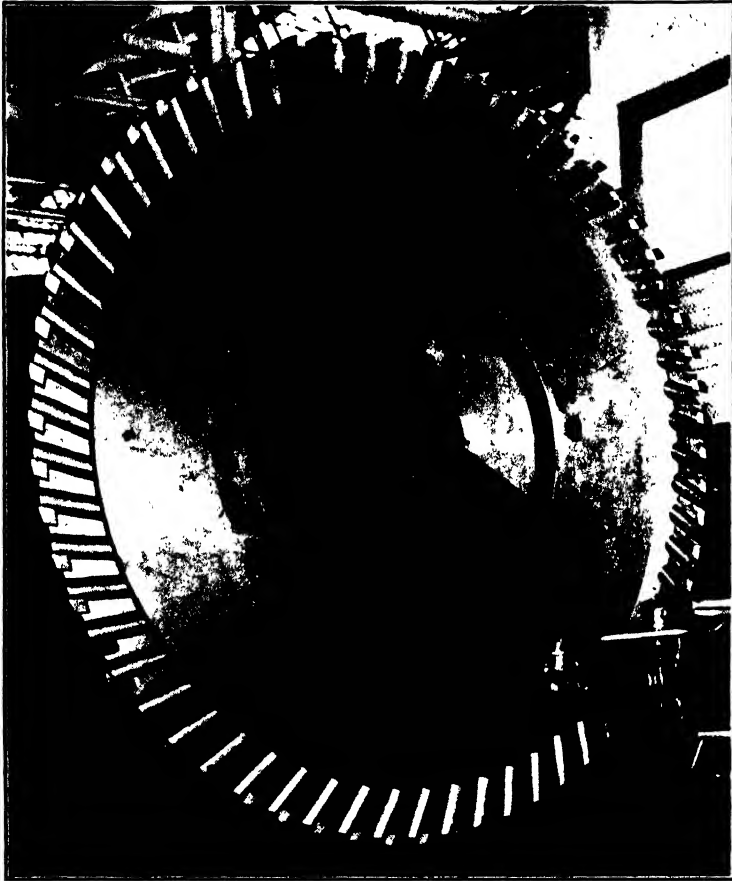
Cemented Carbides. Tungsten carbide was closely followed by a series of other cemented carbides such as tantalum, borium, and titanium carbides. Each of these has a field of use today, but in these fields they have increased the cutting speed more than 300 per cent over any previous best performance of the older-type cutting tools.

Refinements in the use of known carbides have improved the performance of these tools, notably in the number of pieces per tool grind. Tantalum carbide² replaced high-speed steel on a job of turning

¹ Frederick W. Taylor, "The Art of Cutting Metals," *Transactions of the American Society of Mechanical Engineers*, Vol. 28, 1907.

² "Getting Results with Tantalum Carbide," *Machinery*, October 1937, p. 87.

automobile starter ring gears. The gear blank was formerly turned at 40 feet per minute with a machining time of 14 minutes and 35 seconds, producing 50 pieces per grind. The best tantalum carbide



Courtesy of The Ingersoll Milling Machine Company

FIGURE 1. Sixty-eight-inch milling cutter with inserted blades tipped with tungsten carbide. Note small darkened section on cutting point of each insert. Speed on aluminum ingot, 3,000 feet per minute.

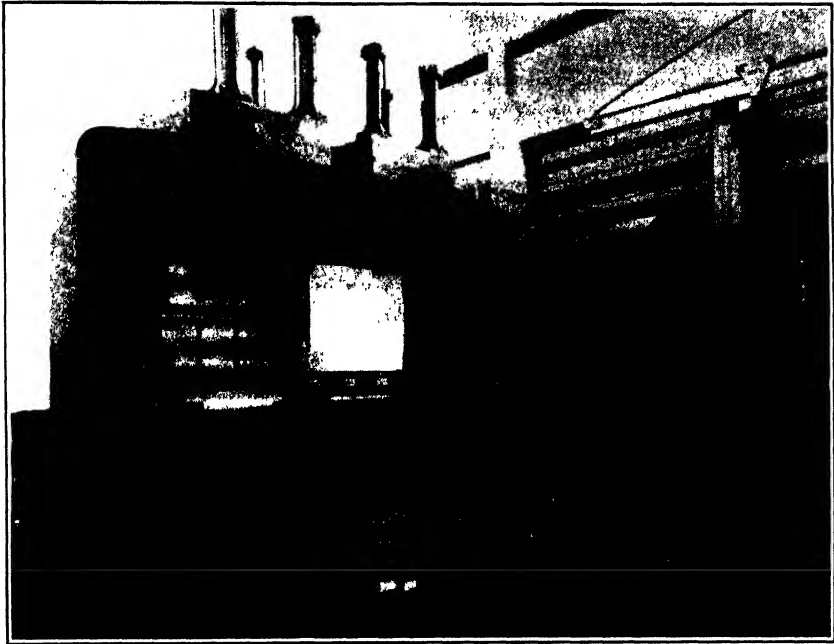
tool turned at 250 feet per minute, took 4 minutes and 35 seconds, and ran 800 pieces before the tool needed regrinding. The finish on the new job was superior to that obtained when the high-speed tool steel was used.

An extra large cutter ³ 68 inches in diameter with tungsten carbide

³ "Huge Tungsten Carbide Milling Cutter," *Machinery*, October 1937, p. 91.

inserted teeth is used to machine the surfaces of aluminum ingots. The cutter runs 3,000 feet per minute with a feeding rate of 72 inches per minute. A 150-horsepower motor drives the milling machine. (See Figures 1 and 2.)

An article⁴ about Carboloy states that, with one exception, the Carboloy Company has not developed recently any new grade of



Courtesy of The Ingersoll Milling Machine Company

FIGURE 2. Aluminum ingot is held by screws. Note drive from motor to cutter spindle.

cemented carbides. It is more important at present to make the current selection and application from existing grades. Better tool grinds, better brazing to hold the tips, and, above all, better machines designed to be rugged enough are increasing the use of the cemented carbide tools. In a machining test a Carboloy tool turned a 0.50 per cent carbon steel log on a Warner and Swazey heavy-duty turret lathe with a tantalum carbide single cutter at the rate of 390 feet per minute; feed $\frac{1}{16}$ inch; depth of cut $\frac{3}{4}$ inch; metal removed at the rate of 3,600 pounds per hour; power consumption 149 horsepower.

⁴ "Progress in the Application of Carboloy Tools," *Machinery*, October 1937, p. 105.

This kind of cutting ability is phenomenal when we remember that a few decades ago often one 10-horsepower motor drove a line shaft which had ten or more lathes all running off the one motor.

The various carbides recently introduced are just under the diamond in hardness. Some metallurgists feel that the improvement in cutting tool materials has begun to approach limiting factors which will make future progress difficult.⁵ If this is true, the possibility of large increases in future cutting speeds may be rather remote. When machines have been improved to the point where they use the entire possibilities of the carbides and when mounting and grinding techniques for these tools are fully developed, engineers may have to look elsewhere for methods of increasing production and lowering costs.

THE ABILITY TO MEASURE ACCURATELY

The development of the ability to measure accurately, particularly lineal dimensions, is directly connected with our industrial development and particularly with mass production and interchangeable parts. In medieval time it was not necessary to have standard measurements because trade was strictly local. The crude standards that did exist helped very little. People who have lived in the country know how much kernels of grain vary in length from year to year and from field to field; yet one of the earliest standards of length was "three barley corns laid end to end to constitute a standard inch." Another standard of length was the yard for measuring cloth, fixed by the distances between a king's armpit and finger tip. In Italy this queer standard was used. On a Sunday morning, the first sixteen men coming out of a church were placed in a straight line with their left feet touching heel to toe. The combined length of their sixteen feet was the "rightful rood with which to measure the land." From these crude methods, the English began to look toward a standard which could be reproduced scientifically. For a time the length of a "second pendulum" was used but this proved to be inaccurate since it varied, depending on its location on the earth's surface. The French developed their metric system, but, because of an inaccurate survey of the meridian through Paris, it is in error. Not until scientific studies suggested the length of light waves was the standard based on a constant that could be duplicated at any time.

⁵ No new cutting tool material has been developed since the first edition of this book (1941). However, new, improved, and more powerful machine tools have been developed to utilize better the inherent possibilities of the cemented carbides.

Methods of Measuring. The methods of comparing articles to be measured with a standard have also gone through an intensive development, through the hand-divided rule, the machine-graduated rule, and calipers, to the micrometer and snap gage, and the various types of optical, liquid, mechanical, air, and electrical comparators. Air and electrical comparators are capable of measuring to 0.0001 inch or better. Manufacturing of interchangeable parts has made it necessary to use tolerances that would have been impossible without modern precision measuring tools.

About 1912, C. E. Johansson of Sweden sent some gage blocks to this country. These blocks were guaranteed accurate to 0.00001 inch per inch. Scientists marveled at their accuracy, but industry saw no extended use for them. When American industries began to make great quantities of munitions for the Allies during World War I, it was found necessary to make these parts in several plants. Quite early it was discovered that, although these factories were usually accurate as far as the inch in their own plants was concerned, the different factories were not working with the same inch. At this point the Johansson blocks came into the picture—but Germany was buying all Sweden could produce. Later the United States Army in conjunction with the Pratt and Whitney Company and the Bureau of Standards developed the Hoke gage to an accuracy of 0.000002 to 0.000008 inch. These gages are compared with known standards by means of light waves. The American system of measurements has been developed to a point where it is possible to measure more accurately than we often can afford to machine.

Excessive Accuracy Means Excessive Machining Costs. J. A. Hall in the *Transactions of the American Society of Mechanical Engineers* discussed the cost of unnecessarily close tolerances. He stated that about 20 per cent of the cost in metal-working shops was due to excessively close tolerances. He gave a number of examples of costs which were reduced by increasing the tolerance without impairing the quality of the product. By calculation of several of the examples shown it appears that the cost tends to be related inversely to the square of the tolerance allowed.

A firm manufacturing small tools received an inquiry for a metal-slitting cutter of the circular disc type. Tolerances were specified to plus or minus one-half a ten-thousandth of an inch. The tool manufacturer quoted \$100.00 each for these cutters. The customer immediately wrote back pointing out that the price was excessive. The tool manufacturer asked the customer to specify the purpose for which the tools were to be used, and requested that he be per-

mitted to use his own judgment as to the accuracy required. If the cutters, when so made, were not satisfactory, he agreed to stand the entire expense. The result was that perfectly satisfactory cutters were made with tolerances of plus or minus one quarter of a thousandth of an inch, which reduced the cost per cutter to \$4.00. The customer's engineers apparently had no conception of the accuracy that was actually required for the work which they were buying tools, nor did they anticipate the cost of the accuracy they demanded.

As just one more example of the cost of unnecessary accuracy may be mentioned the case of a tooling equipment on which a manufacturer quoted; there were four dimensions that were carried to the fifth decimal place, with the understanding that an accuracy of plus one hundred-thousandth inch was required. The tool manufacturer quoted over \$35,000, but after he had persuaded the customer that the four "accurate" dimensions would serve every conceivable commercial purpose if the accuracy was to within plus or minus 0.0002 inch, the quotation was reduced to about \$4,000. These examples taken from everyday manufacturing practice, it is thought, will indicate that there is such a thing as unnecessary accuracy being asked for in the machine shop field. The most valuable quality of an engineer outside of his technical knowledge is a sense of values, the ability to judge when and when not the things that are theoretically possible are, in practice, sensible."

Here again we see a tool of management which is very necessary to mass production in certain fields; yet accuracy in measurement has been developed, in many instances, past the point where the ability to measure close tolerances will help to produce cheaper goods.

DIVISION OF LABOR AND ITS LIMITATIONS

Division of labor has been a powerful method of increasing production and it has been known for a long time. As early as the fifth century B.C., Xenophon writing in the *Cyropedia* summed up the benefits of division of labor as follows: "He, therefore, that is employed in a work of smallest compass must of necessity do it best." One can see that Xenophon had a clear idea of the benefits to be derived from the division of labor. Though his reasoning was correct up to a certain point, the division of labor can be carried too far. In mass production it has often been found advantageous to have one man start

* Discussion of J. A. Hall's paper in *Transactions of the American Society of Mechanical Engineers* by Eric Oberg.

a nail or a nut on a bolt while another man drives the nail home or tightens the nut. This is the limit on division of labor because two or more persons could not share the work necessary manually to start a nail or a nut. In other instances, such as the assembly of a carburetor on a conveyer belt, it was found advisable to combine some operations after an earlier extreme division of labor. This was not because one man could not learn and perform his bit of work quicker and better, but because too large a percentage of his working time was spent in grasping, transporting, and releasing the parts. The percentage of unproductive working time was reduced by increasing the amount of assembly work done at each station. In other words, division of labor can improve the performance of a plant but we must be able to recognize its economic limit.

TRANSFER OF SKILL

The transfer of skill together with the transfer of thought and intelligence has had an important bearing on industrial development. The Industrial Revolution was a fundamental change in the method of production. It involved transferring a part or all of the skill of the workman to the machine. Dean Dexter Kimball in his *Industrial Economics*⁷ has well illustrated the fundamental principle by his choice of a simple drill jig. When a group of metal plates needs a series of holes drilled to definite tolerances, there are several ways in which this can be accomplished. One is to use a skilled toolmaker to lay out each block; by the skilled manipulation of dividers, drill, and special chisel, he can produce the plates, but the cost per plate is high. It has been said that it takes a highly skilled man a long time to do a mediocre job by this method. Today when a skilled toolmaker uses any one of the several methods such as toolmaker's buttons or the modern jig borer, he can transfer his skill to the master plate in which the holes can be bored to any desired commercial tolerance. When these holes are bushed with hardened steel bushings and locating devices are placed on the master plate to bring the holes in proper relationship to the edges of the plate to be drilled, any person, skilled or unskilled, can place the jig and drill the holes. Moreover, the holes drilled by this method will all be interchangeable, well within the tolerance desired, and the cost will be only a fraction of the cost of doing it the other way. Herein lies the character of

⁷ *Industrial Economics*, Dean Dexter Kimball, McGraw-Hill Book Co., 1939, p. 24.

the change wrought by the Industrial Revolution. "*The accuracy of the work no longer depends on the skill of the operator but on the accuracy of the tools.*"

This principle has been the basic thought throughout the entire history of the Industrial Revolution from its inception in the textile industry up to the present day. As long as men are free to think and plan, the transfer of skill to machinery and tools will go on. Each new idea seems to give others a new idea, and change to better methods tends to become geometrically accumulative. In other words, the Industrial Revolution is still going on and probably will continue indefinitely.

BETTER METHODS

The use of new methods as developed by the science of motion study is closely associated with the transfer of skill, intelligence, and thought. Through this tool of management we are able to reconstruct operations, eliminate useless motions, devise auxiliary equipment to aid the work, increase the output, and at the same time reduce the actual output of energy required per man per day. This technique was not fully accepted when it was developed by Frank and Lillian Gilbreth. However, it has now been developed to the usefulness which the Gilbreths visualized in the beginning. The science of motion study is showing industry how to increase production without the usual driving tactics used in the past. Motion study can often increase production on an operation enough to make it unnecessary to purchase the next highest type of machine to do the job. Sometimes the next highest machine has such a large increase in productive capacity that the machine will not be economical because its full capacity cannot be used. As an intermediate step, motion study should be tried first. By ingenious design it has become possible to transfer many highly complicated operations, which formerly required skill, thought, and intelligence on the part of the operator, to automatic machines. Many modern machines have a mechanical memory device which is built into the mechanism. Through such transfer and the application of motion study, industry can continue to find many opportunities to reduce costs and decrease fatigue. Such improvements must, of course, be analyzed from a cost standpoint to determine whether they are economically feasible.

Table 1 shows that industry has increased its output per man-hour substantially in the period from 1919 to 1936. Not all industries have made the same improvement, and it is difficult to say whether the industries with small increases reached their best performance earlier

or whether those industries have become complacent. Normally, the newer industries may be expected to have the greater possibilities for

TABLE 1

IMPROVEMENT IN OUTPUT PER MAN-HOUR DURING THE PERIOD FROM 1919 TO 1936 *

(Not always lowest in 1919 nor highest in 1936)

Industry	Low	High	Improvement in Index Points	
			1929 = 100	% Increase
Agricultural implements	39	118	79	203
Boots and shoes	42	130	88	209
Bakeries (biscuits and crackers)	79	113	34	43
Cane sugar	64	139	75	117
Canning (fruit and vegetables)	77	146	69	90
Cement	60	128	68	113
Chemicals	42	118	76	181
Clay (no pottery)	79	103	24	30
Coke	52	107	55	106
Candy	88	171	83	94
Cotton goods	84	131	47	56
Electric lamps	25	108	83	330
Fertilizers	57	122	65	114
Flour	59	111	52	88
Furniture	60	101	41	68
Glass	59	162	103	175
Ice cream	72	146	74	103
Steel	51	113	62	121
Leather	71	128	57	80
Lumber	87	126	39	45
Motor vehicles	43	115	72	167
Smelting	51	107	56	110
Publishing	56	125	69	123
Paint and varnishes	74	122	38	51
Paper and pulp	60	120	60	100
Petroleum	49	158	99	202
Rayon	77	241	164	213
Rubber	70	140	70	100
Tobacco	68	148	80	118

* Data taken from National Research Project Bulletin on "Production Employment and Productivity in Fifty-Nine Manufacturing Industries."

improvement. The electric lamp industry with 330 per cent has the greatest percentage of increase, whereas the rayon and petroleum industries have 213 and 202 per cent, respectively. Two old industries,

agricultural implements and boots and shoes, however, also have over 200 per cent increase in productivity in this period.

Extensive changes are required to raise the productive capacity of a whole industry 50 per cent. Yet the table shows that eighteen industries increased their productive capacity 100 per cent or more during the tabulated period. Better methods are a powerful factor which should continue to develop for a long time.

NEW MATERIALS

New materials and new uses for old materials should keep the designing and industrial engineer of industry keenly alert to the possibilities of reducing costs and improving the product. New materials are being brought to us rapidly by chemists, metallurgists, and others engaged in organized research work. In its 1937 financial report E. I. du Pont de Nemours & Company reports that 40 per cent of the year's business came from products unknown in 1927. Cast iron formerly was cast from iron number one, two, or three, according to the thickness of the section desired. Today, metallurgists have made it possible to produce cast iron with a variety of physical properties to suit many new conditions. Cast iron* without expensive alloys, but properly melted and cast, has shown an ultimate tensile strength of over 100,000 pounds per square inch. These new properties make it possible to use cast iron for automobile crankshafts, camshafts, and a variety of new uses where it never could have been used in its old form. Plastics, die castings, steel stampings, and drop forgings all have contributed to reduction of cost when compared with other materials used previously in a product. The B. F. Goodrich Company has developed literally hundreds of new uses for rubber; altogether they make 32,000 products in over a thousand lines. Recently the B. F. Goodrich Company announced a "Rorsilader spring" which uses a soft cushioning rubber mounted in place of the usual spring. Road shocks are absorbed in the rubber and do not reach the frame, thus giving a smoother automobile or bus ride. And so on, indefinitely, the march of progress involves new materials and new uses for old ones. As long as we have new scientists and continued research, we shall continue to produce new materials for the engineer to consider in his new designs of old products and of products never thought of before. Industry cannot afford to neglect the constant need to review

* Lecture by Donald Reese of International Nickel Company at Foundry Executives' Conference held December 7, 8, and 9, 1939, University of Minnesota.

its materials of construction for possible reduction of cost and improvement of product.

PLANT DESIGN AND LAYOUT

Since this book is written primarily to discuss the concepts and problems of production control and planning, the important subject of plant design and layout will not be discussed in detail. However, it can be stated that proper design and layout can contribute considerably to a more successful operation of most plants. Layout is closely associated with the study of methods, machinery, and the movement of materials, but in some plants it is under a separate branch of industrial engineering.

In an integrated program of cost reduction the industrial engineer immediately comes to the problem of energy wasted in moving the material unnecessarily during the manufacturing process. This difficulty can be solved by using the facts gathered from motion and time study, production possibilities of new methods and machines, the manufacturing requirements of new materials, and, above all, the manufacturing requirements of the products being manufactured. By recombining or synthesizing all the known facts one can arrive at one or more ideal layouts which will have the lowest over-all cost of production. Keen minds able to think analytically and synthetically are necessary to do a good job in plant layout. Tremendous savings have been made by this branch of industrial engineering, and the job never can be considered finished.

SELECTION AND MORALE OF PERSONNEL

The selection, maintenance, and continued cooperation of the personnel of any industrial concern is one of the most difficult tasks in running a modern industry. We all have our own examples of organizations which have gone ahead with fine morale, overcoming obstacles as they arise. Other organizations getting their personnel from the same community are beset by bickering, petty quarrels, and "buck-passing," which require time and energy to control. The half-hearted cooperation some companies get from their employees results in a constant loss of labor which must be reflected in their costs. In any cost reduction program, therefore, the personnel program should be carefully considered. The selection and maintenance of personnel is a continuous job, and new techniques are being developed by specialists in the field. Such firms as the Procter and Gamble Company which

has an extensive research program devoted to discovering better ways of selecting personnel, the American Telephone and Telegraph Company, and many others are doing fine jobs of selection and maintenance of their personnel by means of special departments set up for this purpose.

The personnel in the factory can be the most aggravating or the most enjoyable factor according to the morale of the group doing the job. The type of leadership has a great deal to do with how well a group can work together. A good organization set up to assign responsibility with authority to people according to their ability to assume it will provide a smooth operation of the plant which no other method will give.

PRODUCTION CONTROL

The composite factor of production control includes a variety of functions and devices which contribute to the successful controlling of the flow of materials through the production cycle. Production planning in all its phases, from the sales estimate for future production to the finished product in the shipping room, is necessary for complete control of factory operations.

The detailed planning, routing, scheduling, and dispatching functions of production control provide a system for production, but it should not be assumed that these four functions are exclusively synonymous with production control.

In any manufacturing enterprise, someone must perform the various functions of production control; whether it is done by a group of specialists or whether it is done by the superintendents, foremen, and workmen is a matter for each organization to decide after a consideration of the costs of each method as related to the results obtained.

This book deals with the problems of accumulating pertinent fundamental information and distributing this information along with the materials for production to the proper work stations so that finished goods can be made according to a prearranged schedule. The system for doing this will vary widely from one plant to another and is not important in itself. Production control has become necessary in modern industry and the tendency toward using a group of specialists for its operation is increasing.

QUESTIONS FOR DISCUSSION

Collateral reading is necessary for best results.

1. Carbon tool steel is the oldest practical material used for cutting tools, yet it is widely used today. Why?

2. Why are the cemented carbides not used more?
3. Assuming that machining to higher degrees of accuracy costs little more, would engineers be justified in specifying smaller tolerances?
4. Are the so-called vertical or industrial labor unions the result of division of labor? Explain.
5. Should engineers transfer the maximum amount of skill to a machine or device?
6. Should the introduction of improved machinery be regulated by law?
7. Can better methods obviate improved machinery?
8. Try to explain the reasons for the low percentages of increase in productivity for some of the industries listed in Table 1.
9. Which new material, in your opinion, has created the most disturbance in the economics of production?
10. Which new material, in your opinion, has given the machine designer greater freedom to do new things?
11. From your own experience, what has been your reaction to the morale of the groups you have worked with?

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CHAPTER III

SCOPE OF PRODUCTION CONTROL

Production control has developed in modern industry largely as the result of the ever-increasing demands made on manufacturing facilities. Chapter I described briefly how the problems of production, like the problems of design, have grown beyond the knowledge and capacity of the mechanic and foreman in the shop. The production facilities of the modern plant operate as a series of coordinated units which must be controlled by people who are thoroughly cognizant of all possible difficulties which may arise from any unbalanced conditions.

Production control may be defined as the coordination of a series of functions according to a plan which will economically utilize the plant facilities and regulate the orderly movement of goods through their entire manufacturing cycle, from the procurement of all materials to the shipping of finished goods at a predetermined rate.

Every plant necessarily controls production in some manner. This book, however, is concerned with the development of a modern concept of controlling production based on a scientific approach. This involves recording facts and information about production, analyzing the results obtained, and basing future action on the analyses.

Variations in the Functions of Production Control. Production control should be considered as a tool of management, used solely to expedite the manufacture of all products at a lower cost and on schedule. If it fails to accomplish this in a particular plant after a reasonable time, it should be discarded in the same way as any other device or plan which is no longer economically sound.

The various functions which must be controlled, in any manufacturing plant, do not differ much from one kind of product to another. The method and extent to which these functions are controlled does vary, however, as several examples will illustrate. The purchasing of materials for production is usually planned and scheduled by production control. But an ordinary brick manufacturer using an adjoining clay deposit for raw material and natural gas for firing the kilns would have practically no purchasing problem and thus few purchasing requisitions for production materials. If we contrast this

to the purchase requisitions which must be written for such industries as the Ford Motor Company and the Western Electric Company, who purchase literally thousands of different production materials, each with definite specifications and a definite schedule of delivery dates, it is easy to see that the purchasing function is always present but varies in complexity.

While purchasing is seldom under the production control group, the latter usually specifies the minimum amount of production material that must be procured and the schedule upon which it must be delivered to satisfy production needs. This information is given to the purchasing department so that its functions will be coordinated with the over-all planning and scheduling which is done for the production departments.

The function of routing (see Chapter XI) also varies widely from one plant to another but for another reason. In certain types of continuous plants, such as cement, flour, rayon, and to a large degree the mass-production plants, such as automobiles, typewriters, and washing machines, the routing function from day to day is almost negligible. This does not mean that the products from such plants do not follow a planned path through their manufacturing cycles. On the contrary, the path the product follows through the plant is usually fixed by careful, painstaking studies before the plant machinery is installed. Only special parts, such as those needed for the right-hand drive automobiles made occasionally, must be routed specially as they appear on the schedule. Continuous- and mass-production plants have men constantly at work on the problem of routing, men who do an extremely careful and detailed job. However, their main responsibility is to prepare the shop layout and routing for new models and changes which occur from time to time. After the routing has been carefully done on any one part or product, an operation sheet is prepared that may remain unchanged for months at a time. On the other hand, small or large plants producing goods in manufacturing lots or to a certain customer's order have the constant problem of routing different parts through the same machines. This requires day-to-day study to keep the machines busy and all the products moving through on a prearranged schedule.

Planning Procedures Vary with Method of Manufacture. Such companies as General Electric and Westinghouse manufacture large turbo-generator units in limited quantities, which may take several years to design and fabricate. In addition, they also make smaller units such as motors, transformers, and meters in large quantities. The Minneapolis Honeywell Regulator Company produces an extensive line of

temperature and humidity control devices. About 20,000 separate parts are needed to assemble the different devices made by the Minneapolis Honeywell Regulator Company. Most of these are produced in manufacturing lots of various sizes. The problem of planning the orderly and economic flow of materials through the productive processes in such plants calls for the best efforts of specialists to prevent chaos.

In addition to these extremes, there are all the gradations in between. It is possible to have orders for one or many pieces which are never intended to be duplicated, or orders for one or many pieces which are duplicated at either regular or irregular intervals. Some companies produce goods under all these conditions or combinations of them, which make it necessary to have trained men for developing methods and procedures to keep the factory producing on the required schedule.

Production Control before Taylor. As discussed in Chapter I the plan used almost entirely up to 1900 was to have the superintendent release the manufacturing orders as they came in and let his staff of foremen get them out the best they could. Broken promises, high cost of goods, and dissatisfied customers often were the result of the old system. When the factory got farther behind, it was the custom to hire more stock chasers or expeditors, as they are now called, to wave telegrams under the foreman's nose, to stress the fact that order so-and-so was already two weeks late, and to state vehemently that if the order was not forthcoming immediately it would be canceled. But since most of the trouble was due to certain bottlenecks in the plant which were not always apparent until the situation was carefully studied, the net result often was to interrupt production and to slow it down still more. It is not difficult today to see why Taylor criticized the system in general use when he came upon the scene. Even after Taylor and his associates proved that jobs could be satisfactorily planned in advance, the idea was accepted slowly.

Production Control after Taylor. Through a number of technical articles, several books, and a series of discussion groups, F. W. Taylor gradually built up a technique and a group of followers to promote better management in metal-working plants. H. L. Gantt, a close coworker with Taylor, contributed the well-known Gantt charts which are used considerably in modern production control systems.

The accepted method today is to build a system or procedure around the plant's operations and personnel which becomes a natural part of the plant. The group trained to operate this control procedure is sometimes a part of the over-all industrial engineering organization.

Through the free exchange, among the industrial engineering groups, of data and ideas such as time study, layout, wage incentives, process analysis, operation sheets, methods, and standards, the production control group can get the necessary information for effective control.

Production control uses information collected by these industrial engineering groups and coordinates it with further information from sales forecasting, factory management, and design engineering or specification departments. All this information is used to control effectively the orderly flow of materials to meet the prearranged production schedule. Where the product is a continuing one, inventories are controlled to satisfy the scheduled requirements with a minimum capital investment. Related factors such as the amount of direct labor, machine loads, and inspection must be balanced and controlled by effective methods of issuing manufacturing orders and by analysis of returns or data from the completed orders. These data or returns must be routed so that interested groups such as cost accounting, payroll, production foremen, and superintendents get all the necessary information promptly.

These various activities start from the sales forecast and end when the goods are shipped from the factory, preferably on the scheduled date.

These functions and others constitute the source and solution of the problems of production control. They must be coordinated and balanced by the application of sound principles, effective methods, and a discipline that will minimize personnel failures.

SYSTEMS FOR PRODUCTION CONTROL

Through an extensive consulting industrial engineering practice and an intensive study of a number of plants which manufacture a wide variety of products, it has been found that plans for controlling the flow of materials vary widely. Practically all plants have some procedure for controlling the flow of production through the manufacturing processes, but in some plants the procedures are not complete or well developed. The author has seen forms used to operate a system varying from simple sheets hand made each morning to an elaborate set of printed forms used to control every phase of the production cycle. The hand-made forms were crude and required the personnel to have prodigious memories and to be on duty continuously because the forms were taken home at night for reference in case the night crew called by telephone with questions. On the other hand, the more complete systems controlled production almost automatically after the forms

were released through a planned sequence of orders and returns to interested groups.

From the discussion thus far in this chapter it is easy to see that the problems of production control vary widely in different plants. For this reason it is not wise to advocate any definite system for all situations. We shall look henceforth at the diverse functions ordinarily connected with the manufacturing cycle and see how these functions vary under different conditions. Methods and devices for coordinating the functions will be discussed but no one system will be advocated in the text. Several examples will be shown of methods for controlling each factor. However, the reader is strongly urged to study his own plant, to decide the extent to which each function is a potent factor in his particular manufacturing cycle, to set up coordinating agencies between these functions, and, finally, to devise a system which will do as much as possible automatically. A tailor-made plan such as this will keep unnecessary production control forms to a minimum. It will distribute the work of the various functions to the people best able to carry the load. It will relieve the foreman and workmen of many clerical duties which hamper their efforts in their main job of producing the product.

METHODS FOR INSTALLING PRODUCTION CONTROL

When the executives of a plant decide to change to a planned control of operations by a centralized group, it is necessary to do so with a firm determination to see it through. Halfway attempts only cause confusion and increase the cost of installing the system. The plan should be well designed and carefully developed to make it work from the beginning.

The management should be ready to support such a system by delegating the responsibility and authority to set up the necessary disciplinary measures to make the plan work. Experience has shown over and over again that the best men with considerable talent and ability will plan the work in their departments independently and act selfishly unless there is a strong and able leadership to coordinate all efforts. To get teamwork of such order requires careful training and discipline.

Installation by Decree. There are two general ways such a plan can be installed. The first one is by decree in which the management suddenly announces a definite plan and orders everyone to conform without further argument. This method fails to get very much co-operation because many executives may not understand the system,

and most of them would resent such high-handed procedure. The top executives may think valuable time can be saved by such a scheme, but a much more workable plan can be developed by appointing committees to help develop the system. This method takes more time in the beginning, but the key personnel of the plant are developed with it and, by the time the plan is ready, almost everyone understands it and is ready to get it into operation.

Installation by Committee. The second plan uses committees of executives who are guided and assisted either by an outside consultant or by a capable man from the plant who has specialized in this work. The committees should include strong, forceful leaders who know how to get things done and who are backed by authority as well as responsibility.

The general committee for investigating the possibility, advisability, and, finally, the methods of installing some plan may be composed of strong representatives from the engineering design, industrial engineering, sales, shop, and cost accounting departments. These men could represent the interests of the main departments and develop new ideas under the guidance of the consulting specialist. These ideas should be presented in a diplomatic way to get the cooperation of the plant personnel rather than enforced consent. However, it is rarely possible to get all individuals in a large organization to cooperate without disagreement. Some will want to continue to run their own show independently of any scheme to make the plant function as a unit. If diplomatic action fails with such individuals, the committee should have a strong delegated authority to discourage such opposition.

Engineering Consultant Aids Committee. The function of the consulting industrial engineer, who may be a staff member or brought in from the outside, should be to steer the committee along a definite path which his experience indicates to be advisable. Here again, the functions to be controlled should be the basis for study. The committee should not be allowed to do too much experimenting. There is a considerable backlog of experience from a variety of plants which can be used as a guide. It is no longer necessary to be a pioneer in this field because cause and effect relationships are fairly well known to engineers trained in this work. It is vital to make extensive surveys of the plant so that complete knowledge of machinery, equipment, tools, layout, product design or specification, personnel, and internal transportation facilities may be known for considered action.

It may be well to remind the committee from time to time when arguments become too heated that scientific management is not on trial in their deliberations. It has proved its ability to reduce costs

and to produce more goods many times, over a period of several decades. If modern management methods fail to work in any plant the men in charge of the installation should be blamed rather than scientific management itself.

To recapitulate, any plant management contemplating the installation of a plan of production control should make the following preliminary preparations:

1. Appoint a strong, diplomatic steering committee to investigate the possibility, desirability, and methods of setting up the control.
2. Furnish experienced help to the committee, either from an outside consulting industrial engineer or from an experienced man from the organization.
3. Give the committee the necessary responsibility and authority to put its plan into operation.

The committee's work will fall into four broad chronological divisions. Several subcommittees can aid in this work, and many individuals, some of them specially placed for the job, can help to collect the information and to make reports to the central committee.

Outline of Installation Activities. The following outline shows the factors to be considered in each of the four steps generally required for the successful installation of a comprehensive system of production control.

The first step involves the collection and analysis of a series of production facts and relationships. Some plants will have gathered and organized many of these through an established industrial engineering department. It may be necessary to make a survey to ascertain whether all the facts and relationships are recent or adequate enough to be of full value. Step one outlines the type of information and preliminary work which is necessary for good production control.

The second step is concerned with the rearranging, organizing, and systematizing of the facts and relationships in step one to provide practical control of shop production.

The third step involves the installation of an organized system for controlling production.

The fourth step is largely one of refinement in which difficulties are studied and changes are made for smoother operation.

**SUGGESTED OUTLINE OF ACTIVITIES TO INSTALL A SYSTEM
OF PRODUCTION CONTROL**

FIRST STEP

Preliminary Analysis, Standardization, and Preparation

1. Develop an organization of fact finders and analysts.
 - 1.1 Select the personnel for ability to analyze complicated personnel and mechanical relationships without antagonizing the people involved.
 - 1.11 Train the members of the organization to be alert in the collection of facts and to present conclusions which can stand the scrutiny of top executives.
2. Analyze the product.
 - 2.1 Analyze the product design or specifications.
 - 2.11 Outline the necessary coordination and cooperation between the production control department and the engineers who design the parts or specify the ingredients for each product.
 - 2.111 Analyze the possible changes and adjustments necessary in design engineering.
 - 2.12 Insist that each part, ingredient, raw material, and final product has a unique number. Any subassembly or intermediate product which is costed or stored regularly for a period of time must also have a unique number.
 - 2.13 Insist that a complete list of parts or ingredients identified by numbers are available to show how subassemblies or intermediates are formed and then turned into final products.
 - 2.14 Develop a "request for change" procedure if necessary, which will formally present to the design engineers the various changes desirable for aiding production.
 - 2.2 Analyze the materials for production.
 - 2.21 Select the proper form or shape of the specified material at the lowest total cost.
 - 2.22 Study the possible substitutes for specified materials, but secure the design engineer's approval before using these materials if the material specifications are changed.
 - 2.23 Classify the materials for record keeping.
 - 2.3 Analyze the adequacy of the ordering, receiving, inspection, and storing of all materials for production. Analyze the methods of issuing and delivering all productive materials to their first operation.
 - 2.4 Analyze the product for low production cost.
 - 2.41 Study the effect of using standard units in various models.
 - 2.42 Study the effect of using standard methods for similar parts.
 - 2.5 Analyze the product.
 - 2.51 Critically examine the design or specification of the product for

- desirable changes to reduce cost or improve performance.
Study alternate design, materials, and methods of production.
- 2.52 Decide on standards.
 - 2.521 Develop standards for handling materials, operations, parts, machine tools, inspection, and labor elements for all current jobs in the plant.
 - 2.53 Write an operation sheet for each part.
 - 2.531 Many of the analyses and standards adopted above are crystallized in the operation sheet which becomes the authority for production and, in some cases, for the compilation of costs.
 - 2.532 Each operation is placed in sequence and described as briefly as possible.
 - 2.533 If any operation is involved or difficult, a detailed instruction sheet may be desirable.
 - 2.6 Study the small tools and other devices which aid production, to determine if they have reduced the cost as much as possible.
 - 2.61 Determine their adequacy for producing at lowest cost.
 - 2.62 Determine the adequacy of the methods for storing and issuing tools; also for delivering tools to the job.
 - 2.7 Study the methods of estimating production and costs.
 - 2.71 Analyze the present methods of estimating the amount of material, labor, and overhead. Study the methods of estimating production per hour and prime cost to arrive at an estimated total cost of the product.
 - 2.8 Analyze current inspection procedures.
 - 2.81 Is inspection inadequate or excessive?
 - 2.82 Are final inspection records coordinated with inventory control?
3. Analyze plant capacity.
- 3.1 Have "as is" production layouts made to study material flow.
 - 3.2 Study the ability of the internal transportation system to transport materials at low cost without damage to the product.
 - 3.3 Study the available machine tools for their economic relationships to production and their possible replacement.
 - 3.31 Examine machine tools for adequacy.
 - 3.32 Examine machine tools for possible obsolescence.
 - 3.4 Make calculations to determine economic feasibility when any changes in plant capacity are contemplated.
 - 3.5 Identify all departments, process centers, tool cribs, stockrooms, machines and work places with a unique symbol.
 - 3.6 Prepare a card file for a complete record of capacity, condition, and productive constants for each machine.
 - 3.7 Rearrange machine layout for better material flow or for changes necessary to accommodate the new plan.

- 3.71 Study the location of stockrooms, tool cribs, dispatch stations, and work stations for possible rearrangement.
 - 3.711 Place raw stockrooms near first operations if possible.
 - 3.712 Place dispatch stations adjacent to tool cribs if possible.
 - 3.713 If departments are isolated from each other, have bays set aside for incoming and outgoing material.
 - 3.714 Place identification symbols.
- 4. Cooperate with cost accounting.
 - 4.1 Analyze present methods of collecting labor and material costs data for the cost accounting group.
 - 4.2 Thoroughly discuss and coordinate with cost accounting desirable changes for improving the accuracy or speed of obtaining cost data.
- 5. During this stage the analysts must work closely with the design engineers, cost accountants, purchasing agents, storekeepers, inspectors, superintendents, foremen, and key workers to get suggestions for improvements and to explain what is contemplated. Finish step one by analyzing the current system used for controlling production.
 - 5.1 Determine the adequacy of each contributing function.
 - 5.2 Study the adequacy of the coordination between related or dependent functions.
 - 5.3 Make a process chart to show how the present forms are used to control production.
 - 5.4 Study the old system to discover which parts of it will be retained or discarded.

SECOND STEP

Organization of the Relationships between the Various Functions Necessary to Control Production

- 1. Coordinate the sales forecast or program with the production facilities.
 - 1.1 Effect of possible employment stabilization programs.
 - 1.2 Effect of sales forecasting on planning for production.
- 2. Organize the planning group to:
 - 2.1 Translate the sales forecast into requirements for raw materials to make the necessary intermediates, subassemblies, and final products.
 - 2.11 Release the purchase requisitions for all materials to be purchased.
 - 2.2 Determine the rate of production for the various materials and parts necessary to satisfy the sales forecast.
 - 2.21 Set dates for the completion of major parts of the production program.
 - 2.3 Determine if present production capacity is adequate or whether subcontracting is necessary.
- 3. Organize a system for inventory control.
 - 3.1 Plan inventories for maximum turnover and minimum or no shortages.

- 3.2 Develop a system for releasing purchasing and manufacturing orders as they are needed to maintain inventories at the proper level.
4. Develop lot-size formulas and charts to help in determining the economical quantity to purchase or manufacture.
5. Organize a scheduling group to:
 - 5.1 Schedule the major steps necessary for completing a large job such as getting a new product ready for production or building a large dam or structure.
 - 5.2 Schedule the production cycle for all materials or units for which the shipping dates have been determined by the planning group.
 - 5.21 This usually applies to special products made in small quantities where the inventory control record is not used for determining the ordering point.
 - 5.3 Schedule the production cycle of all parts requested by the inventory control system.
 - 5.31 Schedules of this type are usually based on the date the material or part must be in the stockroom or ready for the next subassembly.
 - 5.4 Devise methods of scheduling.
 - 5.41 Determine if graphic aids to scheduling are desirable.
 - 5.5 Release orders, after they are scheduled to the proper departments for preparation of the system's papers.
 - 5.51 When the scheduled job to be done is seldom or never repeated it is specifically routed through the shop by a routing group.
 - 5.52 If a standard operation sheet has been prepared in advance, number 5.51 is omitted.
6. Accumulate machine loads for all scheduled orders.
7. Develop standard forms and controls to coordinate the activities of all groups participating in the production cycle.
 - 7.1 Mount control boards where needed.
 - 7.2 Show how orders and returns are routed to systematize the plan.
 - 7.21 Make process charts with instructions to show where all forms originate, where they go, who uses them, and how they are filed or destroyed.
 - 7.22 Show where all new forms fit into a revised system and how old forms are superseded.
 - 7.3 Select a method for reproducing the forms required for each manufacturing order.
 - 7.31 Prepare a written procedure for preparing, reproducing, and distributing all manufacturing order forms to the proper places.
8. Set up the dispatching groups.
 - 8.1 Dispatching procedures.
 - 8.2 Dispatch stations.
 - 8.3 Accumulation points for subassemblies and final assemblies.
 - 8.4 Internal transportation and its control.

THIRD STEP

Actual Installation in the Plant

1. Two common methods used.
 - 1.1 Change over entire plant on a certain date.
 - 1.11 May be dangerous particularly if plant is operating near capacity.
 - 1.12 Is good method if confusion can be avoided.
 - 1.2 Change over one department or a single group of small related departments on a certain date.
 - 1.21 May involve less confusion.
2. Regardless of size of unit changed over at any given time it is necessary:
 - 2.1 To change over all records of inventories, production, tools, and machines to the new forms.
 - 2.2 To start all controls working, including:
 - 2.21 Dispatch boards, tool-crib control, and internal transportation.
 - 2.3 To have short meetings scheduled to explain specific points for superintendents, foremen, and key workmen.
 - 2.4 To issue procedure instructions for the operation of the plan.
 - 2.5 To have a number of trained helpers available in department to answer questions, to educate foremen and workmen, and to aid in the operation of the new plan.

FOURTH STEP

Modification Necessary to Make Plan Work More Smoothly

1. Watch for points where the system seems to be in trouble.
 - 1.1 Analyze the cause of the trouble.
 - 1.11 Refine and revise methods, schedules, duties, and functions wherever there is excess red tape or where the intended control does not work smoothly and more or less automatically.
2. Continue to review methods by motion and time study techniques.
 - 2.1 This is a continuous process and in the best plants methods are always subject to constant revision.
 - 2.2 Control plan should be flexible enough for easy adjustment to new methods and procedures.
3. Watch the forms, scheduled returns, and reports to determine if each form furnishes needed information and actually is used.
 - 3.1 Forms can be revised and sometimes eliminated by this procedure.
4. Gather records of performance.
 - 4.1 Changes in direct labor hours per unit of product.
 - 4.2 Percentages of promises kept by periods.

- 4.3 Percentages of plant capacity used per unit of product before and after production control.
- 4.31 Percentage of plant capacity available for new business can be reported each month.
- 4.4 Effect of new inventory control system on material shortages or surpluses and capital investment.

The following brief discussions of the main topics in this outline will serve to amplify and to clarify some of the outline material. For many topics a thorough analysis and discussion of the procedures in the outline are available in succeeding chapters.

ANALYTICAL ORGANIZATION

In the beginning of this chapter we have assumed that either no organization exists for formal control of production or the existing organization may be suspected of inadequacy. It is also wise to examine any adequate system occasionally to remove or revise any portion of the system which has ceased to operate satisfactorily.

An organized system such as production control, which is and should be critical at all times of the entire manufacturing cycle, should also be critical of its own procedures. If the control of production has been nonexistent or inadequate it is necessary to concentrate on all sections of the first step. After a survey has been made, competent analysts can recommend changes or additional functions to be developed.

PRODUCT

Since the product to be manufactured is the starting point for production control thinking, it should be considered first. If we assume that the product usually is presented for manufacture after it has been designed or its ingredients have been specified, then market analysis and sales forecasting follow later.

Research, Development, Design, and Unique Identification. If the product is of such a nature that it must be designed or a formula developed before the product can be manufactured, complete drawings or specifications are usually prepared for the benefit of the production departments. These drawings or theoretical formulas (sometimes in code) must describe the product completely and must carry unique identification for every part, material, subassembly, or intermediate product and all final assemblies or finished products. Considerable confusion will result if this unique identification is neglected or carelessly done.

Coordination of Product Design and Production Control. Though the functions of product design and the production control departments are completely separate, their spheres overlap at many points. The two departments must have a high degree of mutual respect and a willingness to cooperate. The methods and inspection departments, and sometimes other groups such as inventory control, can find instances where changes in design or specification can materially reduce cost without jeopardizing quality. The product design and production control departments should be so organized that the greatest amount of cooperation and constructive criticism can be obtained with the least friction. They should be encouraged to remain friendly critics of each other.

Although the functions of the product design and production control departments are closely correlated, the departments are seldom directly under the same executives. Design has often been improved by better methods, better machining, or the better use of materials, and control has been improved by innovations originating in the design department. Even if the product is a stable one requiring no design or specification changes, the need for production control still remains. There are hundreds of industries, such as candy, baking, soap, packing, and canning, which have few if any design functions but which have elaborate production control departments. Moreover, production control will be necessary even if, at some future time, all possible improvements in methods, machinery, design, and organization have been made.

Materials. Materials used in the product must be included within the scope of production control because they affect the operation of such a department in many ways. The kind and quality of materials are specified by the engineering design or specification departments, but the problems of having the materials available when needed and utilizing them properly to prevent waste require detailed attention of production control. Before manufacturing orders enter the shop, they must be coordinated with inventory to prevent excessive process inventories on one hand or lack of parts on the other.

The purchasing, receiving, and storing of raw, semifinished, and finished goods must be done under controlled conditions to prevent severe loss. Generally the materials represent rather a high percentage of the total value of a product. Material wasted through improper purchasing, storing, issuing, or processing is money thrown away. Plant personnel should be made to realize that material is crystallized capital.

The methods used to insure the delivery of materials to each production center will vary with the product and type of plant. However, within the limitations imposed by the management, industrial engineers should gather all the facts concerning alternate methods of handling materials and transmit them to the production control group for guidance in scheduling and dispatching.

PRODUCT ANALYSIS

Production control should be established on the foundation of efficient production methods. Although it is necessary to control the flow of materials through a plant whether or not good methods exist, it is far better to have engineers analyze the product for low production cost before or concurrently with the installation of a system of production control.

Product analysis has become almost a necessity in highly competitive and mass-production industries. When the design or specifications for a product are released to industrial engineering for processing, alternate methods of production are analyzed and cost estimates are made. These analyses often indicate desirable design changes to reduce costs. Such studies should be made if costs are a factor in the sale of the product.

Cooperation between the methods and standards group and production control can often emphasize the reduction in cost which can be realized by using standard parts whenever possible. Slight differences in design of several parts are often not warranted when a critical analysis is made. Larger manufacturing lots, fewer special tools, and standard methods in the shop are natural results of such analysis.

Methods and Work Simplification. Time standards are essential in modern planning and dispatching. Much importance has been attached in the past to standard time allowances for every job in the plant. However, if time allowances become a fetish without careful recording of the method used during the timing, the whole program does not mean very much. Too often elements of an operation are carefully timed and resulting standards are set up, when a good motion study may eliminate parts of or even the entire operation itself. In job shops, estimates often must be used to set standards but even in moderate-quantity production it pays to study operations carefully before setting any time standards.

A thorough knowledge of methods used by others, whenever this is possible, and a compelling curiosity to improve established procedures

provide a prolific source of savings. Motion and time studies should be used extensively to promote the search for better methods and to check the suggestions coming from others in the plant.

The importance of a modern motion and time study group cannot be overemphasized in a good production control plan. There are several good books¹ available which adequately discuss the fundamentals of motion and time study. Consequently, no detailed discussion of these important subjects will be attempted in this book.

Study Small Tools. Small tools are the important auxiliaries which make it possible for machines and equipment to produce. The condition and adequacy of these devices often change suddenly in a high-pressure plant.

Small tools should not be taken for granted when a production control scheme is to be introduced. They are important for successful operation of planned schedules. Moreover, the methods of ordering, storing, issuing, and inspecting small tools should be thoroughly examined.

Operation Sheets. Many of the analyses, standards, and decisions from the production analysis are crystallized in the operation sheet. It becomes the authority for the production of the part and the basis for compiling costs of production. When a product is ready to be manufactured and the blueprints or specifications are ready for the shop, the industrial engineering department generally fills out the necessary operation and instruction sheets for each product. These sheets are used to describe the standard methods, the sequence of operations, and standard time each operation requires for all productive operations from the time the material is purchased until it leaves the plant as the finished product. Manufacturing cost depends largely on the proper selection of methods and standards which are written into the operation or instruction sheets. Consequently, only capable people with analytical minds should be responsible for developing these sheets.

In modern shops, operation and instruction sheets are laid down as the procedure to follow. No one is allowed to deviate from them unless his objections are valid enough to have the sheet changed. It would be foolish for any executive to claim that operation sheets are infallible, but he should insist that any contemplated change be fully considered before the operation or instruction sheets are altered. As a matter of fact, design or specification changes, new ideas, and old mistakes make it necessary to rewrite operation or instruction sheets

¹ See bibliography at end of this chapter.

from time to time to keep them current and in line with present practice.

Good up-to-date operation sheets are the very foundation of control in a modern plant manufacturing a continuing product. Before a product can be routed through any department the various operations together with their sequence must be determined. The standard times for performing an operation, either actually timed or estimated, are necessary to set up a list of due dates from which the schedule can be made. After scheduled times of operations are determined, the planning procedure can be executed by the dispatchers who work in conjunction with the foreman to produce the goods when wanted.

Estimating Production and Costs. After the operation or routing sheets have been written, an estimator is often called in to estimate the rate of production for each operation and the material for each part. These estimates are used sometimes to determine if a new product will be commercially feasible in the proposed market. Sometimes the estimated production per hour is used temporarily for scheduling and other purposes until a more accurate time study can be made.

Inspection. In most plants inspection is necessary to check the quality with a predetermined standard. Inspection procedures have gone through an intensive development which has tended to reduce the cost of inspection and to simplify the control of quality.

Industrial engineering records the method of inspection on the operation sheets and designates inspection operations in their proper sequence. The inspection department usually develops inspection methods and teaches the inspectors how to use them. The inspection operations can be scheduled and handled like any other operation by the dispatcher in the department.

The final inspection report for any manufacturing order should state how many good pieces were made and how many were scrapped. These inspection records should be carefully coordinated with the inventory records by a simple procedure.

PLANT CAPACITY

After the product has been thoroughly analyzed and the facts are known, the capacity of the plant should be considered in the light of these facts.

Floor Layouts. The layout of a plant is always easier to study if it is done from a drawing which shows all machines, along with columns, pipes, and other obstructions drawn to scale. The scale often

used is $\frac{1}{4}$ inch per foot. This scale is not too large and yet is detailed enough to give a good picture of a department. Such a layout should show all machines and benches as production centers along with the necessary aisles, tool cribs, dispatch stations, stockrooms, and other auxiliary aids in the department.

An "as is" drawing should be made first, and, from this, possible improvements should be studied and incorporated in the new layout if economically feasible.

Study of Internal Transportation System. The internal transportation system including conveyers, elevators, and hand- and power-operated trucks should be carefully analyzed. Part of the anticipated success of a good production control scheme comes from an adequate internal transportation system which can move material and goods when needed to fit the scheduled dates.

Identification of All Production Facilities. The identification of all machines and production centers, departments, tool cribs, stockrooms, dispatch stations, and any other divisions of the production end of the business should be uniquely designated and labeled with an appropriate symbol.

In addition a complete record should be made of each machine. The working capacity of all production centers must be known before proper schedules can be established. This information is generally placed on "production center data cards" and "operation sheets." The data on physical characteristics for each machine may be placed on two cards which are filed according to machine type and machine number.

Machine Replacement. The productive capacity of any new type of machine on the market but not yet in the plant should be known and periodically checked with the performance of actual equipment in the plant. Whenever savings in the cost of production justify the installation of new equipment, the increased productive capacity often makes changes necessary in production control.

It is also important at all times to maintain equipment in its original condition as nearly as possible.

TIME STUDIES

The information usually transcribed in time studies can be used for a number of things. Time studies should be used more and more as a fact-finding and measuring tool. Companies using them primarily for rate setting are neglecting one of the best sources of shop information. The data on the productivity of machines and equipment

and on the adequacy of small tools, jigs, fixtures, and internal transportation are usually to be found in the time studies in the files. If additional information on productive processes is necessary the time study group can usually supply effective and authoritative data.

There are several good books on time study listed in the bibliography at the end of this chapter. The earnest student should acquire one or more of them for thorough study.

COOPERATION WITH COST ACCOUNTING

The methods used to collect and analyze costs should be studied in conjunction with cost accounting to determine if they are entirely satisfactory.

The cost accounting department is almost always under the accounting division of a business, but the facts concerning labor and material costs are generally available from the various forms used in controlling production.

Any production control scheme should be analyzed for its ability to furnish information and data for the cost accounting and payroll departments. After consultation and cooperation with these departments, the production control forms can be so designed that the desired information will flow more or less automatically to the proper desks.

REARRANGEMENT OF PRODUCTION FACTS TO SOLVE CONTROL PROBLEMS

The second step in preparation for the installation or improvement of a system of production control is to arrange the facts and various bits of information in logical patterns for a solution of the problems.

Coordination of Sales and Production. The coordination of sales and manufacturing is generally considered necessary for good plant production control, and more and more concerns are becoming interested in this problem. The sales policies of a concern definitely affect the production cycle and the method of controlling the flow of materials through the factory. An exchange of information between sales and production far enough in advance to be mutually useful will allow both departments to make their commitments with more certainty. Moreover, improvements in factory operations and reduction in costs can often be obtained by such close relationships between sales and production control.

Organization of a Planning Group. The planning group should coordinate the sales forecast and the requirements for each component

part or material which enters in the product to be sold. The system for planning for all parts and materials along with the machine load should be organized so that the requirements for the current week, month, quarter, or year can be found by consulting the records. The planning file should be organized so that purchase requisitions, manufacturing orders, or subcontracting orders can be released with sufficient lead time to have any material delivered to the shop for fabrication when it is needed.

Routing Group. Job shops working on orders that are seldom or never repeated do not have standard operation sheets. It is necessary to route each job on its own merits after it is planned for the shop's schedule. In a well-organized shop, this routing is done before the various operations are scheduled.

Routing and the writing of operation sheets are the same thing. However, the operation sheet for a part becomes the standard procedure for making that part each time it is made in the plant. When a shop runs a job that is not to be repeated, the routing sheet serves only once, and generally it is destroyed when the job is finished. Naturally, then, the standard operation sheet can be more carefully prepared than the routing sheet for a job that is not to be repeated, because more time is usually available to do a good job on a standard product.

Inventory Control. A perpetual inventory is often the basis for planning and scheduling the purchase and manufacturing orders for products which are produced regularly. This inventory is posted daily to record everything that happens to the supply of any item in the file. Stock issues and receipts, purchase or manufacturing orders, and inventory adjustments are posted as they happen to give a true picture of the current status of each part. This record is sometimes maintained by the accounting department and posted from data furnished by production control. The production control department uses the file or a machine-produced duplicate of it as a guide for releasing orders; the accounting department may also use the file for its inventory accounting.

Economic Lot Sizes. Calculations to determine the quantity to be purchased or manufactured are used to maintain economic inventories and still provide sufficient materials at all times for production. The use of formulas or charts for economic lot sizes are valuable if they are used as an aid for good judgment. They are not to be used blindly, because they are based on certain standard conditions which should be known and occasionally checked by the user of such for-

mulas. When the conditions vary from standard, the economic lot size should be carefully examined for its reliability.

Scheduling and Releasing Orders. The schedule for producing according to plan is maintained and controlled by the scheduling group. This group releases manufacturing and subcontracting orders with scheduled dates to show when the finished material must be delivered to the stockroom.

Machine Loads. After a part or material has been scheduled, the additional load on each machine should be shown on a machine load chart to show how much of the total plant capacity has been absorbed. When certain machine types approach their maximum load, additional shifts must be added, more machines must be purchased, or the excess load should be subtracted.

Standard Forms and Methods of Reproduction. As procedures are developed, forms should be prepared to answer the questions necessary to carry out the procedures and to provide the proper records. Process charts are a great aid in following procedures. They can be made to show all the steps in sequence regardless of who is involved. Moreover, they show what happens to each form. An additional process chart for each individual involved to show his part in the various steps will make it easier for the individual to learn his part quickly.

The methods of reproducing the various forms should be carefully studied to select the one that will give the lowest cost per manufacturing order released consistent with good legibility.

Dispatching and Internal Transportation. An orderly procedure is followed by the dispatchers who follow the detailed schedule in the shop and check on its current status. If any serious deficiency develops the dispatcher notifies the scheduling group for action. The dispatchers operate the control system which consists of orders and returns to all interested groups participating in the manufacturing cycle from raw stock to cost accounting. In addition, the dispatchers often control the internal transportation system for moving the materials from one operation to another.

INSTALLING THE PLAN

The installation of the developed production control system is the culmination of all the preliminary work outlined in the first two steps.

It is quite common for the shop personnel, including the executives, to be rather skeptical and therefore critical of proposed changes in shop procedures. Any good production control system usually shifts executive responsibilities, and thus certain prerogatives may be

changed. If the original steering committee (page 31) has stated its motives and educated the executives as the system developed, the opposition tends to fade away as each step is explained. Process charts should be made to show where each form originates, where it goes, and how it is used to gather and give necessary information. In addition, it is wise to outline the chronological steps each group, such as foremen, dispatchers, and inventory control, is expected to follow for each manufacturing order.

If these preliminary educational measures are carefully worked out, many questions about the system can be answered easily and simply. A group of trained people, available in all departments for several days during the installation of the system, can answer all questions as they arise. Such a program of education and preparation for the installation of a comprehensive production control system will eliminate confusion and make it much easier for everyone to cooperate. If this third step is bungled, it will be much more difficult to get the needed cooperation for a new approach.

POSSIBLE MODIFICATION OF THE PLAN

The most diplomatic members of the production control group who thoroughly know the system should be chosen to act as instructors and trouble shooters during the initial test period. When troubles arise, the difficulty should be analyzed and suggested changes proposed. It is not wise to wait too long before a desirable change is made. In fact, it sometimes gives the skeptic an interest in the plan if he is casually steered to recommend a change.

Excessive red tape should be torn away as quickly as possible. All records and information must serve a necessary purpose. Occasionally the system should be reviewed to keep it in step with major changes in plant policies. Necessarily it must be flexible enough to include the constant revisions in methods and procedures which are common to all progressive plants.

Records of Performance. Any department, and especially a new one, must show justification for its existence after a certain trial period. "Before" and "after" records of performance which can show improvements are of real service both to the company and to the department. The remainder of this book will discuss in detail the various topics and subtopics outlined in this chapter. As far as possible these topics will be discussed in sequence, but occasionally it will be desirable to combine the discussion of several topics or to correlate the

several aspects of a topic in one place rather than to follow the exact pattern and sequence of the outline.

QUESTIONS FOR DISCUSSION

1. Do any plants operate without some kind of production control?
2. What type of products require routing sheets written as required?
3. Discuss the effect of manufacturing methods on the various functions of production control.
4. At what points is strict discipline necessary to make production control work?
5. Why should the committee plan of installing production give the best results?
6. What are the preliminary functions of a committee appointed to investigate the need for a new production control system?
7. Name the major departments which can contribute information or services for good production control.
8. Discuss the necessary arrangements and precautions during the actual installation of a new system of production control in the shop.
9. Name the functions of production control which you consider most important in a manufacturing plant with which you are familiar.

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CHAPTER IV

ORGANIZATION FOR PRODUCTION CONTROL

The organization for production control has a variety of forms in different industries and plants within industries. Regardless of whether the functions of production control are gathered together under one organization or not, someone, somewhere, must perform most of these functions. Under the old "foreman, order chaser, mechanic" system of manufacturing, the foreman was held responsible for all details necessary to get the product delivered on time. Although the foreman was responsible he failed at some points because he lacked the broad information necessary to do a good job. In addition, the foreman had so much work to supervise that he allowed the mechanic to do too much of the detail for him. The level of ability at some points was insufficient to handle the technical problems involved in the production of modern goods.

Since the functions of production control are essential, modern management feels that it should be organized and performed by personnel with the requisite training, experience, and discipline. It is as wasteful to have an expensive mechanic haul his own material or get his own tools as it is to have him try to devise methods for production after a job is assigned or to set up schedules for its completion. Unorganized control of production involves several hidden costs, including too much or too little inventory, loss of plant capacity owing to preventable lost machine time, mechanics' wages spent for unproductive waiting, and amateurish planning done by the mechanics or the foreman. Costs are usually less when mechanics and production workers are used to keep process centers busy at all times for production. The overhead costs per unit are thus reduced.

How the organization should be set up, to whom reports should be made, how extensive the system should be, and how thoroughly it should attempt to predict, establish, and control production are matters to be decided for each plant.

The detailed organization for any given plant must be arranged according to the importance of each control function. In addition the personnel available to be assigned to production control often makes it necessary to rearrange functions in what may be considered

unorthodox groupings. In this way, particularly in smaller plants, an individual carries a combination of functions which he can do best. Moreover, in quite small plants one properly trained individual may be able to take responsibility for all phases of production control.

Department Name. Production control is known by several other names such as engineer of manufacture, planning department, planning and control, or production department, depending upon local conditions and nomenclature. The head of the department is usually responsible to the plant industrial engineer or the production manager as a staff man and works with foremen or superintendents only indirectly through daily manufacturing orders, individual conferences, and committees.

Qualifications and General Duties of the Department Head. The head of such a department should be an industrial or mechanical engineer with professional training in factory work and business. It is important to have the head of the production control department in a responsible position. He should be able to supervise the setting up and the enforcing of such things as manufacturing and purchasing schedules, inventory records, economic lot sizes, and the routing of parts in job shops. He should be in a position to insist that shop practice agrees with the written operation sheets.

The general supervisory duties listed below become the responsibilities of the department head.

1. Determine the material requirements (raw and finished) for the estimated production of each salable product. This is done by using the bill of material or formula to compile the amount and form of materials needed per unit of product. Once this information is compiled for a product, only the design or formula changes need be considered to keep the requirements up to date.

The extent of the production program may be set by sales forecasts, production programs, customers' orders, or plant capacity. The material requirements per unit is then multiplied by the number of units to be manufactured in the period of, say, one, three, six, or twelve months.

2. Post the perpetual inventory control. The inventory quantities may be based on the order point and lot size, the balance available, or the requirements. Data to be posted come from copies of material requisitions when stock is released, purchase requisitions when released to the purchasing department, purchase orders when released to vendors, inspection reports when materials arrive in plant, manufacturing orders when released to dispatcher, inspection reports showing the

number of good pieces made, and scrap reports as furnished by inspection.

3. Plan the release of purchase requisitions, manufacturing orders, and rework orders to allow sufficient time (except in emergencies) before the material is actually needed for production. By using the information in the inventory control, the planner determines the amount needed for each order and the date the material is wanted for production. In addition he usually is responsible for the follow-up to see that the delivery dates are met. If the orders are for a job seldom or never to be repeated, the planner tries to meet the delivery date set by the customer as relayed by the sales department.

4. Route the sequence of operations, specify tools and machines, and estimate the time required for each operation for all parts or materials released by the planner on single job orders. This routing function is not necessary for manufacturing orders when the part or material is included in the regular manufacturing program since this information appears on standard operation sheets.

5. Schedule the dates for each manufacturing order. It sometimes is desirable to schedule the starting date for each operation to provide a good check on the progress toward the desired delivery date.

The scheduler posts machine load charts from data on the routing or operation sheets. Reports to the management concerning lack of plant capacity for projected manufacturing programs or excess plant capacity for new business may be derived from machine load charts. He also maintains progress data on jobs scheduled, either by tabular or graphic means.

6. Prepare all paper forms for giving and collecting information concerning each manufacturing order. Distribute these forms along with necessary blueprints to the proper dispatchers and to other departments such as cost accounting.

7. Dispatch the various manufacturing order forms such as requisitions, move orders, time cards, tool notices, and inspection reports to the proper persons. Dispatchers often act as clerks for the payroll and cost accounting groups to compile the time spent on a job by each man and the total time for each man per week.

In conjunction with the foreman the dispatcher releases and closes jobs for each productive worker under his jurisdiction. The dispatcher reports idle machines, material shortages, tool shortages, lost time, and completed jobs to the central scheduling groups or to the foreman.

8. Move men are often under the dispatchers to expedite the necessary movement of material between operations. The move men get

their orders from the dispatch station and report back to the dispatcher when a move is completed.

Unless the production control department head has complete authority to supervise these shop activities, any production control system will break down and may as well be abandoned quickly before more money is wasted on it.

Figure 1 shows the usual relationships between production control and other departments and divisions. This chart does not show lines of authority but flow of information between the various groups. In some cases arrows indicating flow of information point both ways. This means that orders and returns are going both to and from certain groups. This chart is general in character and should be used only as a suggestion for approaching each plant's production control problem. The numbers on the connecting lines in Figure 1 are explained below.

1. In most plants, the productive activities are based either on predicted or actual sales. If the product is made to order, the production control techniques differ slightly from those used for a regular product. Predicted sales or sales forecasting provides information for a tentative production program which is studied, formulated, and released, generally by the general manager after conferences with production, sales, and sometimes the engineering managers.

2. If the production program involves a new product, it is necessary to get complete parts and materials lists, along with the necessary blueprints. Old products are assumed to be the same unless new specifications are released or notification of their pending release is sent to industrial engineering well in advance of scheduled production dates.

3. The new production program is broken down by production control to calculate the amount of raw and purchased finished materials needed for the entire program. Often this is planned for delivery by periods to avoid excess inventories. Requirements for finished parts, subassemblies, and final assemblies are planned and scheduled for action in the plant by periods.

4. Inventory control records are set up or maintained for each material, part, subassembly, and final assembly. If completed assemblies are shipped as fast as they are made, there is generally no reason for production control to post a finished goods inventory control on them. The inventory is posted from any data that affect the control, such as purchase requisitions, purchase orders, receiving reports, manufacturing orders, inspection or work completed reports, stores requisitions, allocations, and requirements.

8. The raw materials, usually for the first operation, and the tools for the various operations as called for on the operation sheet are called for at the stockroom and tool crib and delivered by the move

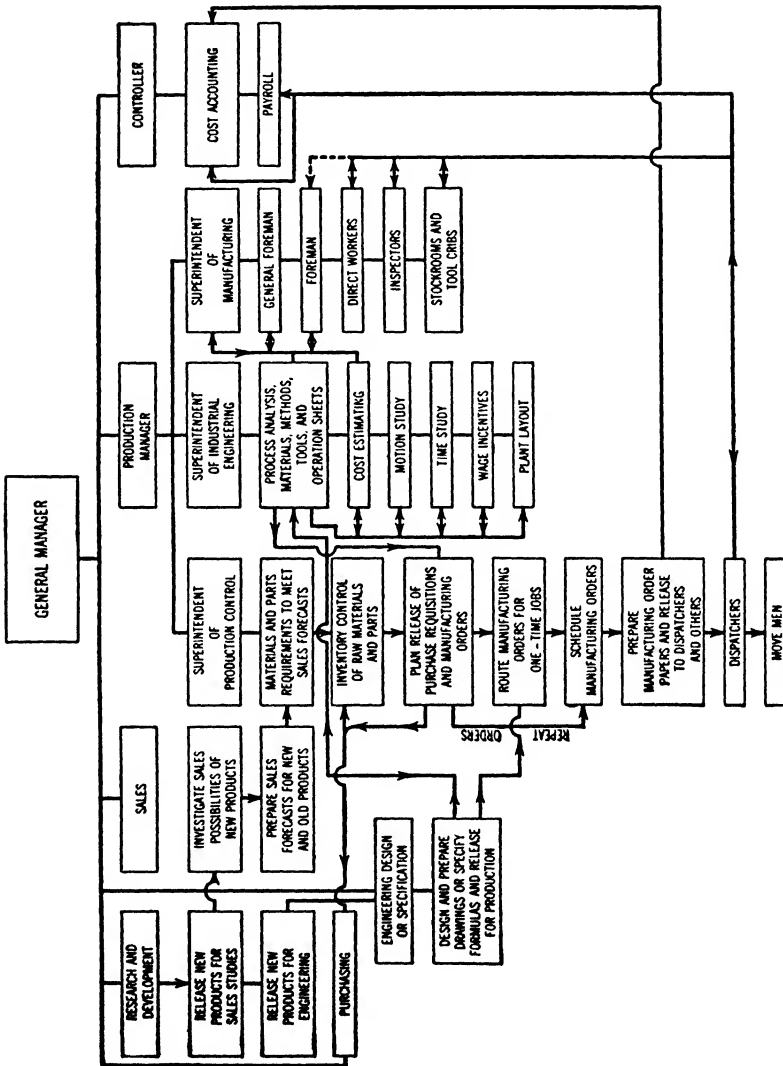


FIGURE 2. Lines and arrows show the interrelationships between production control and other groups and departments.

men to the scheduled operation as requested by the dispatcher. The tools are returned to the tool crib by the move men when the operation is finished. In addition the move men deliver work in process to the next operation as requested by the dispatcher.

9. Inspection, if any, is often on the schedule and administrated by the dispatcher like any other operation.

10. Inspection reports, if any, are often used to post the inventory control for the number of good pieces made and to record the number of pieces delivered to the stockroom.

11. Scrap reports from inspection are sent to the production methods group for analysis. The average amount of scrap pieces is the basis for the material overage percentage. (See the operation sheet of Figure 8, page 218.) This is used to show how much additional material should be released to get the required number of good pieces.

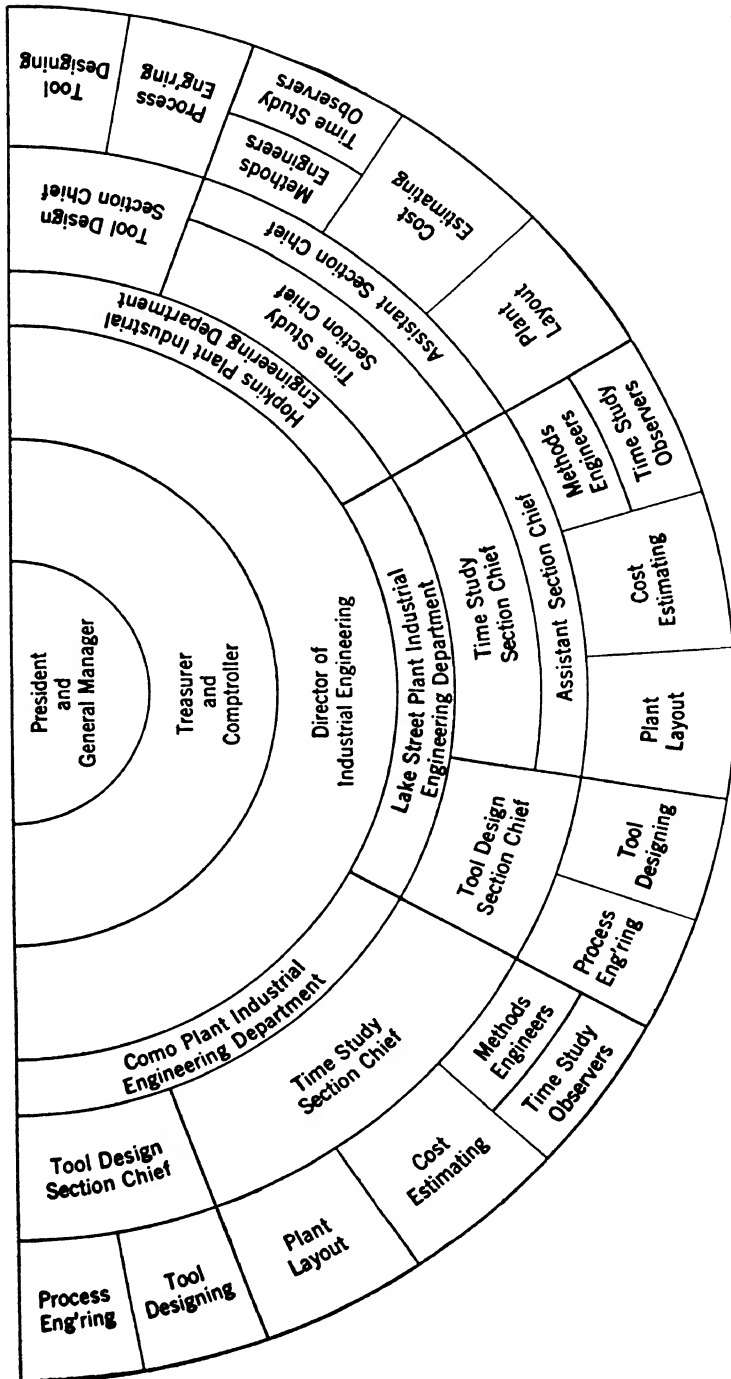
12. The job card for each operation with the elapsed time on it may be sent to cost accounting from the dispatchers by messenger. In some plants the payroll department is interested in the job card also.

13. The material requisition for each manufacturing order may be sent to cost accounting from the dispatchers by messenger. If standard costs are used this probably is not necessary.

14. Production control's record of shop activities is posted from the dispatcher's record of performance on each operation. Thus complete information on shop progress can be obtained from a central source without a search through the shop by expeditors.

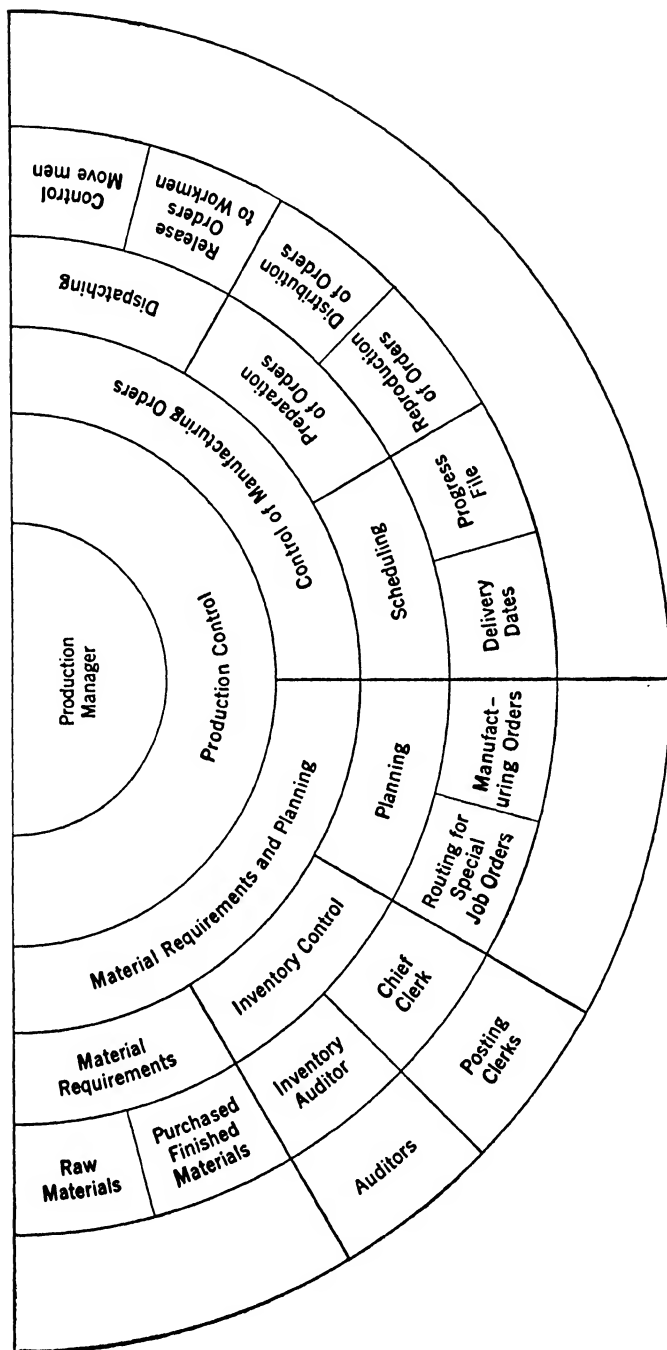
Figure 2 is another general chart showing the interrelations of production control with other departments. The various lines show the flow of information between the various groups; in some cases, the information is exchanged in both directions.

It is often difficult to convince the line executives that production control has been designed to help them. When the foreman discovers that he can no longer hire and fire his men under the slightest provocation, that he must work closely to a prearranged schedule, that machine loads are determined in advance so that parts must follow a certain sequence, that tools are selected and, in many places, are ready when the job is started, that other people besides himself are going to check the work for quality, and that the speed of production is determined by a group of time study men, he feels he has lost all his prerogatives and is headed for oblivion. It is not difficult to understand why the foreman feels this way because under the old system he spent most of his time jumping from one thing to another in an effort to keep up with the clerical and expediting duties imposed upon him. Today he does not have less to say about how a job should be run, but the policy is determined in advance by discussion with all interested parties. Once established, this policy is operated by clerical help who take over most of the detail from the foreman. The modern foreman is then free to do a better administrative job than ever before.



Minneapolis-Moline Power Implement Co.

FIGURE 4. Enlargement of the industrial engineering sector of Figure 3.



General Aniline & Film Corp.

FIGURE 5. Production control's position in the organization of a plant employing about 300 mechanics.

Figure 3 is a new type of organization chart ¹ which shows the relative position of production control and industrial engineering in the plant. The director of industrial engineering is on a par with plant superintendents; they appear in the same sector in the chart. Production control for each plant is under the plant superintendent.

Figure 4 is an enlargement of the industrial engineering sectors shown in Figure 3. The blank sectors in Figure 3 have been left for future expansion.

Figure 5 is an organization chart of the production control department in a metal-working plant employing about 300 mechanics.

QUESTIONS FOR DISCUSSION

1. Discuss the qualifications and general duties of a production control supervisor.

2. Should the same general organization for production control be adopted by plants making similar products?

3. Should a foreman have the privilege of disregarding the amount and scheduled date as specified on a manufacturing order?

4. Discuss the flow of information between the various groups cooperating in a production control system.

5. Can the shop with adequate production control get along with foremen of less ability?

6. Should the functions of production control ever be decentralized?

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¹ Devised by Alfred E. Fixter, director of industrial engineering for all plants of the Minneapolis-Moline Power Implement Company.

Chapters V through XIII discuss preliminary analysis, standardization, and preparation considered desirable for good production control.

CHAPTER V

PRODUCT DESIGN OR SPECIFICATION

Research in Industry. Research, together with its ultimate application to salable products, is one of the greatest contributors to the advancement of our standard of living. If the products developed by research can be made in large enough quantities and cheaply enough to be widely used, another contribution has been made to a higher standard of living. During the last two decades, industry has applied more and more scientific knowledge to a wide variety of production problems. The number of persons engaged in industrial research has increased more than six times since 1921.

Time Required for Inventions to Reach Full Importance. In a report of the National Resources Committee concerning the social implications of new inventions already in use or just being developed, the Committee stressed the possible effects in the next ten to twenty-five years. It pointed out that many years usually elapse before a major invention has any great effect on the national economy. Usually the great inventions become important only after years of contribution from a large number of separate inventors. Methods of manufacture which bring down the cost must be developed so that a widespread market can materialize. The first automobile came in the 1890's, but the industry did not greatly affect the nation until about twenty years later. Television is not yet in widespread use although it was first conceived in 1877. Transmission of pictures by wire required eighty-eight years to become important. The airplane took seventy years and talking pictures forty years before they became commercially successful.

The point made here is that inventions playing an important part in our national economy required a long time to make their far-reaching changes felt in the lives of our people. Consequently there is plenty of time for our manufacturers, businessmen, social workers, and politicians to make the necessary adjustments before the effects are felt.

Demand for Product. Too often signs of approaching change are neglected or even ignored by those who are eventually affected most. Modern industry cannot feel secure unless it knows by investigation and research where its product or services stand in the future demands of the nation. Sometimes industries try to strengthen an outmoded position by a negative type of advertising. When electric headlamps were first accepted for automobiles, the acetylene industry advertised widely the foolishness of such a move because it was unreliable and therefore unsafe. The building industry has permitted the development of high costs and has charged all the traffic will bear on everything from materials to final fabrication. This industry is now fighting the introduction of prefabricated houses by advertising the benefits of the old methods. Often the money spent for such advertising would yield far greater returns if spent to find out what the industry can do to keep in step with any new factors which affect its business. The acetylene gas industry wavered several times when its market was threatened, first, by electric automobile lamps and, second, by electric arc welding. Each time the industry has found new and expanding uses for its product by research methods. Electric welding requires a large number of plate sections cut by the oxyacetylene torch. More gas is required to cut these shapes than formerly was used to weld by gas. Research has paid in many ways for the Union Carbide and Carbon Corporation, producers of the fundamental material for making acetylene. Over half their record-breaking business and over half their profits are from a wide range of new products which did not exist twenty years ago.

Results from Introducing New Products and Materials. The new products which have no relationship to any older product, except probably to compete for a share of the consumer's dollar, are not so difficult to combat as the newly developed products which are substitutes for known stable products. Electric razors are competitors of the blade-type razors; synthetically colored quartz granules used in coating asphalt felt roofing material have driven the inferior natural granules from the market; electric refrigerators and ice refrigerators have been battling for several years, with the ice group apparently losing the fight. The manufacturers of the older products may suddenly find their markets dwindling unless they are forearmed by a carefully planned program of research and constant development.

Invention is the great disturber; investors and bankers may well look into the future of applied science in fields of agriculture, mining, transportation, communication, and many lines of manufacture to keep in touch with developments. The National Resources Commit-

tee reports show that other studies should be made of thirteen seemingly important inventions to ease the necessary adjustments caused by their widespread use. They list: (1) the mechanical cotton picker, (2) plastics, (3) the photoelectric cell, (4) air conditioning, (5) synthetic textile fibers, (6) synthetic rubber, (7) television, (8) prefabricated houses, (9) facsimile transmission, (10) gasoline from coal, (11) new types of airplanes, (12) soil-less agriculture, and (13) automobile trailers, as the important developments to watch.

Such predictions are not always valid because, although ideas may look important, they do not always develop as planned. The automobile trailer, for example, did not develop so quickly as was expected. For a while, many people purchased trailers as a fad, but this expansion was short-lived. There seems to be a tendency at present toward a sounder development in the use of trailers to relieve the housing shortages due to the rapid expansion of industries in some cities. In addition, more people are learning how to use the trailer for housing after retirement and for recreational purposes. As another example, the very need for large amounts of cotton may diminish when and if synthetic fibers can replace it. If this happens, the mechanical cotton picker will die with the cotton crop.

Value of Inventions. Long-range predictions of which inventions will be important are precarious. Some of the most promising fall down during development; others may be outmoded before they are fully developed. What happened to the process of making paper from cornstalks? Where are the full-sized cars which were to run forty or fifty miles on a gallon of gasoline? Why did automobile trailers fail to remake America? All these proposed developments and many others failed to come up to their press agent's expectations because something unforeseen happened. Cost of production may be a hard problem; customer reaction may be unfavorable. Technical difficulties may be on the verge of being solved, but any one thing may hold up the entire development. For instance, Diesel engine development was held up until dependable metals and atomizing nozzles were available.

Research prevents a company from becoming obsolete in its field, and at the same time it stimulates business by making old processes, old products, and old machinery obsolete. For instance, the present-day methods of finishing flat surfaces by broaching or coining have made some of the older methods obsolete for mass production. The consumer benefits because broached surfaces are cheaper and better. Even the manufacture of such a prosaic product as a surface-coated abrasive has been improved by constant research, both fundamental

and applied. The cutting properties of the abrasive grains were improved considerably by use of an electrostatic charge to deposit the mineral on the glue-coated backing. The grains are impinged against the backing at high velocities and are oriented by an electric charge so that the long axis of the grain is perpendicular to the paper or cloth. Considerable experimental work was necessary before commercial results were accomplished, and extensive changes in manufacturing technique were involved, thus affecting many phases of the business.

From Research to Manufacture. As mentioned earlier in this chapter, the possibility of commercial development and exploitation of an original idea discovered by fundamental research may take years of incubation before the product is ready for wide sale. Management is, by nature, conservative, and a study of the products which have come from research indicates that the future value of the findings of research is often not apparent at once. In some instances, barriers have been placed or allowed to remain in the path of further development.

It has been recognized that the progress of such basically new ideas is hampered by the lack of human foresight and omnipotent judgment. The average, commercially minded manager is reluctant to take over a new untried product during its developmental state until its market and profit possibilities have been determined.

Trial Stage and Pilot Plants. To improve this unsatisfactory condition, many plants have an intermediate process of development which produces and sells the product during the trial stage. This intermediate stage carries the product through the incubation process to determine if it can be made economically. Usually the products thus produced are sold in a trial area to determine how the public will react. Chemical industries have used such pilot plants for years to develop new processes. Many other industries are taking over the same idea to test the commercial possibilities of promising new products before large sums are risked on a possible economic dud.

When the dentifrice Teel was placed on the market by the Procter and Gamble Company, it was sold only in the Chicago area for some time until they were satisfied the public liked the product. In the meantime, the plant was geared up to supply the nation when the time came for widespread distribution.

Design Function Not Always Needed. There are a great many industries which do not need an engineering design department. Such industries as vegetable or fruit canning, artificial ice, and brick, need to specify or design very little for any of their products. Such indus-

tries as the paint, soup, soap, bread, candy, baking powder, dye, and chemical industries often need rather elaborate specifications and formulas for each product made in the plant. However, not much actual designing is necessary for these products, so that the engineering design function is not needed.

The specifications and formulas are made by chemists, chefs, or other specialists, depending on the product, and usually are filed away and issued with the manufacturing order. The Eli Lilly Company has the formulas for each of its medical preparations carefully recorded on a tracing which is used to make the blueprints for the manufacturing order. At all points in the manufacturing cycle, the various instructions necessary for an order are written on the tracing so that no mistake can be made in the blueprinted directions for each department.

The clothing, shoes, gloves, jewelry, and similar industries have designers who generally work from sketches from which patterns are made for the various sizes. These patterns are usually the basis for cutting the raw material. The patterns are filed away and issued with the manufacturing orders.

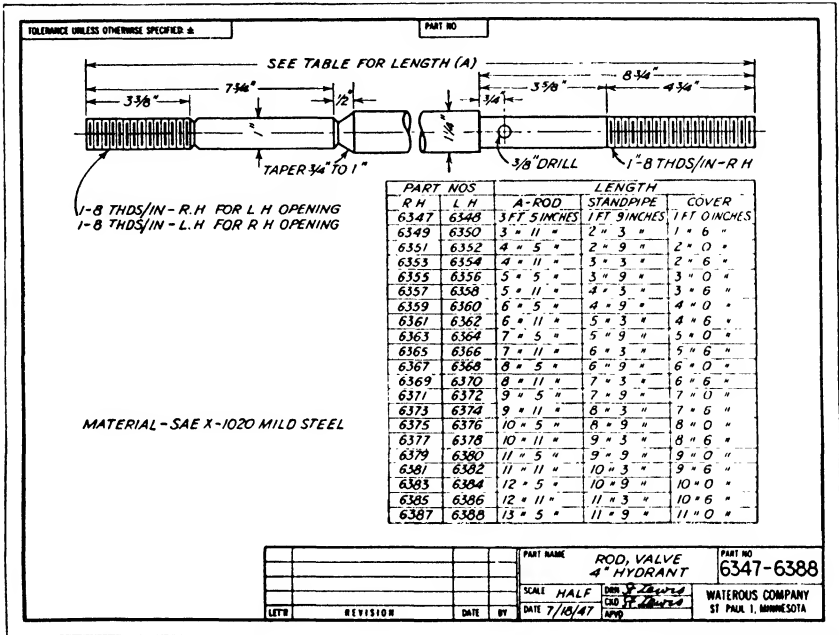
Design Department and Production Control. In the metal, wood, plastics, and similar industries there are generally engineering design departments responsible for the original design. These departments must be sure that each part is strong enough and suitable for its function; consequently this group specifies the material. All necessary information such as proper material, correct dimensions, and tolerances must be on the blueprint. Moreover, special processes like heat treating, plating, or other finishes should be described or coded on the print for each part.

The complete drawings are finally released for production after a few units have been built and tested to find out if the idea is sound. If a research department has developed a product up to a certain stage, the engineering department generally studies it carefully from a commercial engineering point of view.

When the product can be made on general-purpose machine tools such as lathes, shapers, or milling machines, a few are first made by ordinary hand methods. These are tested, redesigned if necessary, and worked over and over to eliminate what are known in factory parlance as "bugs."

Many of the modern products are then turned over to a design stylist who will beautify the product and make it appealing to the customer's eye. A farm tractor concern once called a style designer

to make its tractor look lower, more powerful, heavier, and, at the same time, streamlined for beauty. To the satisfaction of the company, the stylist succeeded in doing all these things by altering the outside of the tractor. It appeared heavier but actually was lighter than the old model. After the design has been accepted, the blue-prints are prepared and sent to the process analysis group of indus-



Waterous Company

FIGURE 1. Example of tabular method to show many similar part numbers on one drawing.

trial engineers where the product is studied for methods of manufacture.

This process is not used in all plants, but, generally, if production is very great or if it becomes very complex, it is necessary to make complete drawings. To reduce processing time and to help eliminate the possibility of errors caused by confused drawings, it is commonly considered best to have only one part on each print. Some plants modify this rule slightly where a family of parts have the same appearance but differ in size. In this case, a tabular approach for the various dimensions with a unique part number for each sized part will often reduce the actual number of drawings required. Figure 1 illustrates how this may be done.

Production control in all its phases is easier to set up and maintain if adequate and easily read blueprints or specifications are available for all products.

Blueprints Are Necessary. Only about twenty years ago, a concern, now with worldwide distribution of its product, was attempting to manufacture a complicated product without the use of blueprints. The procedure for developing the new product was as follows: When someone in the organization had an idea for a new or improved instrument, this idea was transmitted verbally to the experimental department. The experimental department consisted of highly intelligent skilled mechanics who developed the idea and produced a finished instrument. The completed instrument was tested for performance; improvements were usually suggested by the test; and it was built and rebuilt until an instrument emerged which would pass the test of good performance. So far this practice agrees fairly well with modern practice except that no drawings were used in the development stage.

However, in its later stages the method used by this company deviated widely from current practice. When the instrument was finally approved and accepted, it was disassembled piece by piece and each component part was wired to a board for future reference. This part board, as it was called, was used as a substitute for modern drawings. If 100 instruments were to be made, the mechanics in the production shop were told to make enough pieces like the ones on the board to make 100 instruments.

Let us consider what would happen under this method because of lack of drawings and control. Each mechanic measured the part he was to make, set his own tolerances, and decided on his own method and sequence of operations. If the part was to be made from brass, he or the foreman would select a bar of brass as close as possible to the largest diameter of the part. (Specifications for brass vary tremendously.) The shop was on piecework so it was quite common for the parts with the best price to be made in greater quantities than needed while the parts with tight piecework prices were delayed because the mechanics avoided them. Even with simple instruments and comparatively low output, this system was failing to work successfully. When the firm began to assume leadership in its field, one of the first things it did was to make complete drawings of all its parts.

More recently, a concern making a large line of mattresses and upholstered furniture decided to expand its operation. Under the old plan of manufacturing in one building, the firm could get along without drawings because the output was low and variety was small. Each foreman knew the entire line and usually managed to remember the

different parts. When the increased production was decentralized, however, to four buildings in four nearby towns, the lack of identification of parts proved to be very troublesome. It did not mean anything when the inventory clerk in Plant H ordered a medium coil spring hooked on both ends. This company quickly had to place engineers on its staff to aid the line officers in the manufacture of the product.

Blueprints Should Be Authoritative. The only justification for blueprints and specifications is to provide a positive record which tells all the facts needed to produce a part. These facts should be plainly written in unmistakable language and arranged as simply as possible. More and more concerns are following the practice of showing only one part on each drawing so that confusion and mistakes are lessened. To avoid mistakes in the shop, *no prints* should ever have *notations written* upon them after they come from the duplicating process. If any prints are in use with pencil marks or notations on them, no one is sure of why they were changed and no one can be held responsible for possible mistakes. Mechanics working under this system of corrected prints have been known to change a dimension to cover up a mistake in machining. The drawings, specifications, part lists, and all other information coming from the engineering department should be completed in the engineering department before the original tracings are duplicated. When changes are necessary, they should be made on the originals, the date of change noted, and duplicates delivered by the engineering department to all stations having the drawing in their files.

At the same time the old print in the files should be *removed* and *destroyed* before the new one is placed in the file. Prints replaced in the production control office should not be filed but should be referred directly to someone whose duty it is to look over all changed prints for possible changes in shop procedures. In this way the print files throughout the factory will contain only the latest prints, and obsolete parts made because of the use of obsolete prints in the shop will cease. All engineering changes should be sent to the production control department immediately and to all interested superintendents and foremen. In some job-lot production shops, a new print is made for each manufacturing order. Thus the danger of using obsolete prints in the shop is entirely eliminated. The production control department changes its records and procedures to conform to the engineering changes and sends out this information to all concerned.

A formal request for change (see Figures 2 and 3) will help to reduce pencil notations on blueprints, part lists, and operation sheets

in the shop. When industrial engineering, production control, or the shop desires to have a drawing or specification changed, an avenue is open for them to present their request with reasons to the engineering office. It must be assumed, of course, that engineering is the final judge of the soundness of such requests. On the other hand, no engineering group can afford to neglect suggestions and criticisms from the persons who use the blueprints. If the request is turned down, the reasons should be clearly stated on the form which is returned to the originator.

Form: Eng. 260D

MINNEAPOLIS-MOLINE POWER IMPLEMENT COMPANY

REQUEST FOR CHANGE TO DRAWING OR BILL OF MATERIAL

Machine_____ Part No._____ Date_____ Sheet No._____

Name_____

BM. No._____ Sheet_____ Line_____ For_____

Description of Change_____

Reason for Change_____

Request by_____ Gen. Foreman_____

Approved for Machining: Tool Dgn. Supv._____ Methods Dept._____

Approved for Casting: Pattern Foreman_____ Foundry Supt._____

Approved by Engineering_____

Use Reverse Side for Remarks (Return if rejected)

FIGURE 2. Example of request for change for engineering drawing or bill of material.

Sometimes the normal difference of opinion, which is quite common between engineering and production, is allowed to assume unhealthy proportions. The following excerpts from an article¹ illustrates what happens if the balance and check between departments is not maintained.

¹ "Let the Shoemaker Stick to His Last," *American Machinist*, Vol. 89, No. 26, December 20, 1945.

REQUEST FOR CHANGE

Date 4/1/47

If change is rejected, return to the originator and state reasons as follows: _____

A committee including Engineering, Production, and Sales can do the job. It gives the sales executives a chance to suggest methods

or designs that can become sales points, the engineer a chance to suggest methods or materials that may be strange and new, the shop man a chance to suggest less exacting tolerances or cheaper methods through slight redesign. No one man nor his group has ever had a monopoly on ideas, even in a specialty. These groups work better as a team toward a common goal. Here are ironed out the differences in opinion, the artificial distinctions, the efforts to grab control. The system is being successfully used in many companies—wherever the men who comprise the committee are big enough and broad enough to allow anyone to offer a suggestion in good faith.

This indicates the need for broader training in engineering, in the practical application of ideas as well as in their evolution. The graduate engineer must have all the theory he can master, plus the practical training to apply, or at least understand the application of, his ideas. He must, most of all, have an open mind, willing to consider the ideas and theories of anyone, whether or not he wears a white shirt or has the proper degree after his name. We must break down the last vestiges of the wall between theoretical and practical knowledge, merging the two for mutual benefit and without suspicion or condescension on either side.

NOMENCLATURE AND IDENTIFICATION

The production department is directly concerned with the design and specification of materials for the product only so far as they affect production possibilities. However, positive nomenclature and identification are the very life blood of a successful control system. Therefore, it is essential to have a positive and unique system to keep every part, tool, material, work station, and department clearly identified through all the stages of manufacture. There are several systems of identification in use. The best for any one plant is the simplest one which will do the entire job without chances of errors owing to the system.

Classification and identification of the product must originate and be carried on by the engineering department. It is rather difficult to set up a plan showing too many things unless the product is stable. The engineering department of a company building toasters attempted to have the first two numbers of a series such as 37AB391 indicate the year the part was first made. The letters AB were to designate the model for which the part was designed in 1937. The series of numbers after the letters formed the part number. If this system had been analyzed before it had been adopted, its failure would have been revealed. Parts designed in 1935 for toaster model EP were found

perfectly good for the 1946 toaster model PQ. Thus, the present model toasters are made from a series of parts whose identifying symbols have lost their meanings. It is impossible for this firm to drop the first two numbers and the middle letters because the last numbers are not unique, since they were repeated for every year and model when new parts were designed. Thus the company is tied to a parts number system which has lost its original meaning and which has become unnecessarily cumbersome and hard to file.

In certain types of industries such as the furniture industry, where the customer seldom or never calls for spare parts after using the product, each part can have a number or symbol and after some period of time, say two or five years, the series of numbers can be repeated without difficulty. In other types of industries, however, such as automobiles and typewriters, numbers for spare parts as well as for parts in active production must be kept unique. The straight numerical system is capable of unlimited expansion and often is used.

The numerical system has several variations which can be used for part identification. The Dewey decimal plan, widely used in libraries, has possibilities of indefinite expansion. However, its greatest use is in classification of such things as tools and accounts. The straight number plan is widely used for identification of parts because it has unlimited possibilities of expansion and is universally understood. Where products are made from many pieces, some of which are used through one or more model changes, it becomes difficult to build up a system of numbering the parts that will have significance for long if too much information is included in the part number. For unique parts used on only one product, it is possible to use letters in the identification to designate the product, such as CO23, designating part 23 for a can opener.

When only one part is shown on each blueprint, the part number and drawing number are usually the same. The number is then called the part number. Some firms, particularly job shops, have more than one part on each blueprint. In this case, the drawing has a number which identifies it. Each part on the drawing then must have separate identifications, usually a letter. For example, the drawing number could be 10008 and the parts on the drawing designated by A, B, C, and so on. Thus 10008A could mean only one part, and confusion in records, costs, and inventory could be entirely eliminated.

The production control department, machine and assembly departments, stockrooms, inventory control, and others who work with any kind of part lists have difficulty unless each part has a unique part

number. Even variations, such as right- and left-handed parts or parts that are similar except for size, should have unique part numbers.

MINNEAPOLIS-MOLINE POWER IMPLEMENT COMPANY
 Revised July 9, 1946--Sheet No. 1
 Replaces Sheet No. 1 dated Feb. 14, 1946

BUNDLE LIST
FOR
MODEL "S" SELF-PROPELLED HARVESTORS

	No. Bds.	12-Foot		14-Foot	
		Grain Tank	Back Plat.	Grain Tank	Back Plat.
Complete Shipment.....	1	4222XT	4222XS	4223XT	4223XS
Hood over Straw Spreader....	1	1970X	1970X	1970X	1970X
Spout for Grain Elevator....	1	2022X	2211X	2022X	2211X
Sickle.....	1	2263X	2263X	2189X	2189X
Reel Bearing and Clutch.....	1	2190X	2190X	2190X	2190X
Reel Spider (3) & Divider					
Guards (2).....	1	2191X	2191X	2191X	2191X
Reel Shaft and Sickle Pitman.	1	2264X	2264X	2192X	2192X
Reel Blades (6).....	1	2265X	2265X	2193X	2193X
Header Auger, R.H. (Radiator Side).....	1	2266X	2266X	2194X	2194X
Header Auger, L.H. (Grain Tank Side).....	1	2267X	2267X	2195X	2195X
Grain Elevator.....	1	2196X	2208X	2196X	2208X
Straw Spreader.....	1	2197X	2197X	2197X	2197X
Harvestor Body, with Engine, Tank, Center Header Section	1	2199X	2238X	2199X	2238X
Right-Hand Section of Header (Radiator Side).....	1	2305X	2305X	2303X	2303X
Left-Hand Section of Header (Grain Tank Side).....	1	2306X	2306X	2304X	2304X
Tool Box.....	1	2213X	2213X	2213X	2213X
Reel Support, Braces, Truss, etc.....	1	2308X	2308X	2307X	2307X
Vertical Header Truss.....	1	2262X	2262X	2262X	2262X
Bag Chute.....	1	No	385X	No	385X
Platform, Hand Rail, Shields and Support.....	1	No	2209X	No	2209X
Braces, Rods, Gusset, etc., for Platform.....	1	No	2212X	No	2212X
*Pneumatic Main (front) Wheel for 8-Ply 11 x 24" Tire....	2	2202X	2202X	2202X	2202X
*Pneumatic (rear) Wheel for 4-Ply 5.50 x 16" Tire.....	2	1871X	1871X	1871X	1871X

***NOTE: Wheels to be on Harvestor**

FIGURE 4. Example of farm implement bundle list.

A safe rule to follow is: If any part, no matter how similar to another, cannot normally be used interchangeably in all aspects with the similar part, the two parts in question should have individual, unique

numbers. This concept of unique part numbers is important for good control, and executives responsible for controlling production should insist that design engineering furnish them. Engineering design must be responsible for all classification and identification of the product because they are the only ones who know the product well enough in the beginning to do this.

Subassembly Nomenclature. In many plants whenever two or more parts are assembled and usually held for temporary storage the assembly is designated by a unique number. This prevents the subassembly from ever losing its identity for separate planning, pricing, costing, or accumulating for later completion of another subassembly or the final assembly.

Parts List. The engineering department also should issue what is variously known as a parts list, drawing list, or model list to show the parts included in any unit to be manufactured. When the product is large and must be shipped in separate units, it is a good plan to have all the parts going into each unit listed together on one or more sheets with a unique subassembly name and number. All the planning, from purchasing of material to the accumulation of the separate parts for the subassembly and the final shipping procedures, can be closely followed and controlled. Figure 4 shows a list of bundles required to make a composite bundle number 4222XT for a 12-foot grain tank. This complete shipment consists of the nineteen separate bundles comprising the subassemblies necessary for the 12-foot grain tank attachment for the Model S self-propelled harvester. Each of the separate bundles under the number 4222XT also has a list of the parts constituting the bundle. Figure 5 shows the parts list for bundle number 2190-X. It is common practice in the farm implement industry to ship the parts for various attachments in bundles wired or boxed together so that the dealer or user can assemble them as needed.

For any product made of more than two parts, a parts list is necessary for good control. This parts list should be complete to the last screw, washer, and nut. In addition it should show the parts in groups as they are assembled to make the various sub- and final assemblies. Figure 6 is an example of a parts list which shows all the drawing numbers used to make the final assembly of a 1 horsepower electric motor. Figure 7 is an example of a graphical parts list showing how the various parts are combined to make the several sub- and final assemblies. This sort of parts list is of great value to the shop and production control organizations, particularly when

PARTS LIST

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REVISED		MINNEAPOLIS-MOLINE POWER IMPLEMENT CO.	
11/30/44		DIVISION	REEL BEARING AND CLUTCH BDLE.
		B. OF M. FOR	"S" HARVESTOR
		DATE	2/28/44
		ORDER NO.	
		B. OF M. SHEET NO.	

	DESCRIPTION	PATTERN NO.	PC. PER MACH.	MATERIAL	SIZE ROUGH BAR STOCK	SUP. PLIED BY	REMARKS	LINE NO.
1	Reel Drive Clutch	5335-S	1	Assembly				1
2	Reel Shaft Bearing	5475-S	1	Assembly				2
3								3
4								4
5	Reel Drive Chain	795-S	1	94 x #51 PL.	ST. LKS.	P		5
6	Guard over Reel Shaft	3820-K	1	03105	#20 GA. 8 1/2" x 11 3/4"	S		6
7								7
8								8
9	Annealed Wire		1		#13 x 8 FT.	P		9
10								10

Minneapolis-Moline Power Implement Co.

FIGURE 5. List of parts for bundle 2190-X as called for in Figure 4.

PRODUCT DESIGN OR SPECIFICATION

DRAWING LIST & SPECIFICATIONS		FOR		MODEL NO.		5 SCR 204 C 1	
COMPLETED BY	<i>Spagnoli Sept 22-39</i>	INSPECTED	<i>Branco Sept 29-39</i>	REQ. NO.	P.O.		
MOTOR		TYPE	FRAME	FORM	POLES	H.P.	SPEED
STANDARD		SCR	204		4	1	1760
Wool Packed Bearings		H'T OF IRON		2"		BORE 5 7/8"	
SAME AS M.L.		EXCEPT					
	TITLE OF DRAWING	DRAWING NO.	GR. NO.	UNIT	REQ. QUAN.	DATE	NOTES
1	End Shield (C. E.)	K 3902504	1	1			
2							
3							
4	Quadrant Cover (Solid)	P 2981480	1	2			
5	Quadrant Cover (Vent.)	P 2981480	2	2			
6	End Shield (P. E.)	K 3902505	1	1			
7							
8							
9							
10							
11	Stator (Wound)	K 3938378	1	1			
12	Conduit Box Assem.	K 2105282	1	1			
13							
14	Rotor Wound	K 3938378	1	1			
15							
16							
17	Brush Rugging	K 3902517	1	1			
18							
19							
20	Pulley	★ M 3114251 PT	204	1			
21	Sliding Base (* 204)	★ T 3785569	1	1			
22	Belt Tightener	★					
23	Connection Label	See					
24	Crate Label	S.I.P. - 37506					
25	Name Plate						
26							
27	Outline	L 60941		×			
28							
FOR REFERENCE ONLY							
30	White Print	GEM - 600	NOTES				
31	Test Spec.	3132490 - 3					
32	Innul. Test Spec.	S.I.P. - 37511					
33							
34	Stator Conn. Diagram	S - 20046 - 2					
35	Br. Yoke Conn. Diagram		NAME PLATE STAMPING FULL LOAD AMPERES _____ FULL LOAD SPEED _____ TEMPERATURE _____				
36	External Conn. Diagram						
37							
38							
39	Brush (2 Pairs)	V - 2919474					
E7	Bearing Lining (C.E.)	For V - 1782031					
P12	Bearing Lining (P.E.)	Supply V - 1782031					
Mo*	Thrust Washer	V - 2935811					
Mo?							
M20	Air Gap	.012"					
M28	★ TO BE FURNISHED ONLY WHEN CALLED FOR ON REQUISITION						
CHANGES							

General Electric Co.

FIGURE 6. Drawing list for a standard motor showing parts and required quantity of each.

PARTS LIST

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Master Parts List for Final Assembly Number 910

Part number	1st Sub-assembly number	2nd Sub-assembly number	3rd Sub-assembly number	4th Sub-assembly number	5th Sub-assembly number	Numbers in Final assembly	Final assembly number
581						581	
21						21	
392							
396	19						
405							
10							
33							
36	240	18					
92							
37							
50	93						
			609			609	910
215							
303							
396	709						
407							
408							
196							
208	733						
79							
83	801						
601							
		902				902	
392							
458	896						
603							
401							

FIGURE 7

the product is a new one just going into production. Figure 8 is an amplification of the graphic parts list idea. It includes a portion of page 30 to show the machine graphic assembly index with the part numbers in sequence. Figure 9 is a portion of page 14 which shows the machine graphic assembly chart. This assembly chart shows

MACHINE GRAPHIC ASSEMBLY INDEX						
PRINT MASTER - PAGE NO. 30						
PARTS ASSEMBLY LEGEND FOR SUBASSEMBLIES						
PART NO.	INDEX	DESCRIPTION	MAT'L.	RAW STOCK NO.	SIZE	QUAN-TITY
12115	50-I-30	Insulator—Door			1 by 23 by 72	2
12116	50-J-36	Knob	Catalin			2
12419	21-J-44	Hose Tracing Separator "R"				1
12420	2-J-27	Transformer Unit				1
12422	2-J-35	Transformer Cover, Upper	CRS		090 by 9 $\frac{1}{2}$ by 13 $\frac{1}{4}$	1
12423	2-J-40	Transformer Cover, Lower			090 by 11 $\frac{1}{16}$ by 13 $\frac{1}{4}$	1
12424	2-I-7	Transformer Panel Strap	HRS		$\frac{1}{8}$ by 2 $\frac{1}{2}$ by 16 $\frac{1}{4}$	2
12426	2-I-9	Transformer Panel	Black Bakelite		$\frac{3}{4}$ by 2 $\frac{1}{2}$ by 6 $\frac{3}{4}$	1
12427	14-I-34	Gear Housing Assembly				1
12428	14-H-33	Sprocket		Purch	KSA 16	1
12429	14-H-35	Drive Shaft Tracing Sep	Acc Stock		500 by .005 by .52 $\frac{1}{2}$	1
12430	14-H-36	Spacer Bearing Trac Sep	Seamless St Tubing		1 $\frac{1}{16}$ o.d. by .521 i.d. by 2	2
12431	14-I-37	Bearing Torr Needle			Bra-B	2
12431	20-I-16	Needle Bearing		Purch		2
12432	14-H-27	Gear-Drive Shaft Trac Sep Assy				1
12433	14-F-26	Spur Gear			ND 21B	1
12434	14-F-28	Std Steel Bushing			$\frac{5}{8}$ o.d. by 1 $\frac{1}{2}$ i.d. by 1 $\frac{1}{4}$	1
12437	19-I-25	Spur Gear				1
12438	19-I-4	Tank Suction Assembly				1
12439	19-I-3	Tank Tube				1
12441	16-I-13	Duct Separator	St St			1
12441	19-H-2	Duct				2
12442	19-H-1	End Plate				2
12443	12-I-49	Angle Support Separator Assy.	L			1
12444	12-H-47	Angle Support Trac Rec	Steel Angle		$\frac{3}{16}$ by 1 $\frac{1}{2}$ by 1 $\frac{1}{2}$ by 4 $\frac{5}{16}$	1
12446	19-H-48	Stud Support Trac. Rec. Tray	CRS		$\frac{5}{16}$ Dia by 1 $\frac{1}{16}$	1
12446	12-H-48	Stud Support Trac Rec Tray	CRS		$\frac{5}{16}$ Dia by 1 $\frac{1}{16}$	1
12447	9-I-49	Angle Support Tracing Sep Assy	R			1
12448	9-II-17	Angle Support Trac. Rec. R	Steel Angle		$\frac{3}{16}$ by 1 $\frac{1}{2}$ by 1 $\frac{1}{2}$ by 4 $\frac{5}{16}$	1

FIGURE 8. Example of a graphic parts list index.

how the parts go together. Note the sample part number 12431-1 in both Figures 8 and 9.

Figure 10 shows how the same idea can be used to develop the flow of material and quantities required for a chemical product.

Although the design or specification department almost always specifies the grade and kind of material, the gross quantity or size of raw material to use is often calculated by the production control department.

Cooperation between Production Control and Engineering. Engineering and production control must have close cooperation and a high degree of mutual respect. If any necessary information on the

drawings or specifications is incorrect, incomplete, or not clear, the product analysis group of industrial engineering should send a change request to the design engineers at once. Mechanics and workers in the shop have the right to assume, after the prints have been checked by design engineering and the process analysis group, that all mistakes

SHEET 3 OF 3 SHEETS

FOR

PART NO. 13914 Left End Plate Assy

7548-1 Adjusting Screw Assembly

12432-1 Gear-Drive Shaft Trac Sep Assy

12427-1 Support-Drive Shaft Trac Sep Assy

7378-1 Chain Guide Assy

13914 Printer End Plate Assy

MACHINE GRAPHIC ASSEMBLY CHART

PAGE NO.

14

SUBASSEMBLIES

DESCRIPTION	SUB - ASSY NO.	NO. REQ'D	A	B	F	H	I	ASSEMBLY LINE	K	L												
Spur Gear		1			12433-1						26											
Gear-Drive Shaft Trac Sep Assy	12432-1	1					12432-1				27											
Std Steel Bushing		1			12144-1						28											
Allen Hd Cup Plt Set Screw		1			16						29											
Sprocket		1				4376-1					30											
Taper Pin		1				7120-1					31											
Taper Pin		1				12293-1					32											
Support-Drive Shaft Tracing Sep.		1				12428-1					33											
Support-Drive Shaft Trac Sep Assy	12427-1	1					12427-1				34											
Drive Shaft Tracing Sep.		1				12420-1					35											
Spacer-Bearing Tracing Sep.		1				12430-1					36											
Bearing Torx Needle		2				12431-1					37											
Hex Hd Cap Screw		3					107				38											
Lock Washer		3					11166-1				39											
Bracket-Chain Guide Support		1					12922-1				40											
Rd Hd Machine Screw		2					210				41											
Lock Washer		2					11165-1				42											
Chain Guide Bracket		1				7377-1					43											
Chain Guide Assembly	7378-1	1					7378-1				44											
Chain Guide		1				7376-1					45											
Rd Hd Steel Machine Screw		2					211				46											
Flat Washer		2					11157-1				47											
Lock Washer		2					11165-1				48											
Hex Nut		2					337				49											
Printer End Plate Assy Left	13914	1						13914			50											
Hex Hd Cap Screw		1					129				51											
Lock Washer		4					11168				52											
Hex Nut		4					343				53											
OZALID	MODEL PM	ASSY NO.	See above	WRITTEN BY	GB	DATE	1/5/48	CHECKED BY	WOS	DATE	1/12/48											

FIGURE 9. Parts list arranged to show how an assembly is put together.

have been found. In some cases, the design engineers or specification writers are interested in the methods and operations chosen to produce the product. If the degree of excellence demanded by the drawings or specifications has not been met owing to poor methods or faulty sequence of operations, the design or specification engineers should send a change request to production control at once. By such a system of checks and balances both design engineering and production control are checked for their mistakes as quickly as possible. These two groups work better as a team toward a common goal. They can

iron out their differences in opinion and thus prevent efforts to control the other's domain. Such teamwork is being successfully used in many companies wherever the men who comprise the team are broad-minded enough to accept suggestions.

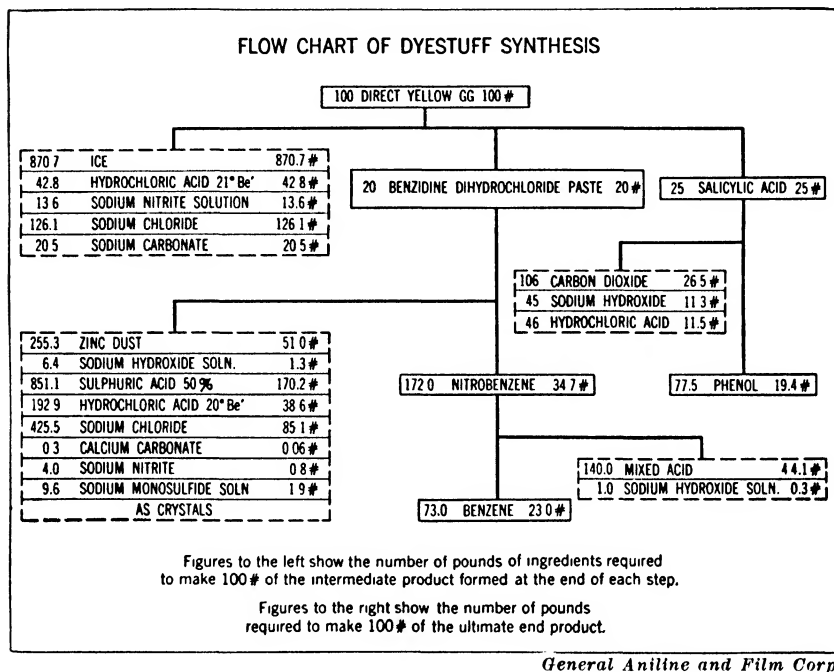


FIGURE 10. Graphic chart of ingredients which is useful for production control

QUESTIONS FOR DISCUSSION

Collateral reading is necessary for best results.

1. Why do some people believe that new machines and products should be controlled by legislation?
2. Name an important invention which was commercialized quickly. How did it succeed?
3. How can research keep the old products of a company in the profit-producing group?
4. What important recent invention, in your opinion, will cause the greatest shock to our social life if the invention becomes widely used?
5. When should research work be commercialized?
6. How does a manufacturer know when a new idea has commercial possibilities?
7. Why does the shop prefer to have the privilege of changing blueprints? Why is this a bad procedure?

8. Who should be responsible for classifying and identifying the product?
9. Can the Dewey system be expanded indefinitely and is it desirable for production work?
10. What types of industries must carry spare parts on hand?
11. How do drawing or part lists aid production control?

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CHAPTER VI

MATERIALS, THEIR CLASSIFICATION AND SELECTION

Materials for Design and Specification. It is difficult to do the best job in production control without a good general knowledge of the materials used for the product.

The engineering design department is primarily responsible for the specification of materials. To be able to specify them, the design engineer must know the tensile, torsional, shearing, and compressive strengths of all materials used in mechanisms and structures. Often other physical qualities such as electrical conductivity and resistance, hardness, magnetic quality, elasticity, resistance to constant heating and cooling, heat conductivity, expansion coefficient when heated and cooled, ductility, ability to take various finishes such as paints, lacquers, or plating, and many other qualifications in certain applications must be considered in selecting materials for various products.

The list of materials continues to grow. Not only have new families of materials been created, but old families such as steel, cast iron, and glass have had many additions which are available for the design engineer's consideration. Beryllium copper and glass, for instance, have been used for springs, and in certain applications they are far better than spring steel even if the magnetic qualities of spring steel are not objectionable. The family of plastics is already large but frequent additions are being made. An outstanding example is a new plastic which is hard and transparent enough to be used for ground lenses. It is lighter than glass and will not break nearly so easily. These new materials should be carefully explored periodically to be sure nothing is overlooked which will make the present product better, cheaper, or perhaps both.

In the chemical and process industries the choice of materials is also about as wide as it is in the mechanical industries. A number of changes and substitutions are made in formulas and specifications either because of acute shortages, economic conditions which make certain materials too expensive for a time, or new chemical materials which can improve the product. The chemical field has a number of materials which have similar properties for certain uses. For example, several chemicals develop a silver image on a photographic film

or paper. In some processes they may be used more or less interchangeably, but in others adjustments must be made in the entire formula if a substitute is used. The synthetic dye industry is a complicated and exact science, but substitution and permanent changes are made in various formulas which may improve the final dye or produce the same dye at lower cost.

Materials for Economic Production. The production engineer is more generally interested in other properties in addition to those mentioned above. Materials provide the beginning for production control. There are literally thousands of kinds of materials used in modern factories. They are in solid, liquid, and gaseous forms. They are toxic and non-toxic. Some are very cheap, whereas others are very expensive in cost per pound. The shipping, storing, care, fabrication, and reclamation of waste vary greatly with the cost of raw material. Some industries use large quantities of precious metals, jewels, and expensive chemicals; others may use only clay or iron ore. Some materials are very easy to transport; others are difficult to transport. Various materials machine easily or not at all. Some are explosive under certain conditions; others are always a fire hazard; some require no special care. The list of properties of materials which interest the production man could be expanded whenever we think of another industry. Yet these properties or lack of them seriously affect the production possibilities in many factories.

The product analysis group, generally associated with industrial engineering in the mechanical industries, should critically examine the design engineer's choice of materials. This is usually done when the methods of manufacture and the equipment are specified in the original writing of the operation sheet. The chemical and process industries have the same problem when the formula or specifications are turned over to the plant for manufacture. Production-minded chemical engineers develop equipment and processes which will make the laboratory product in large-scale production equipment. Often this involves changes in pressures, temperatures, and even in ingredients to some extent. In any event, someone must decide how a product is to be manufactured, and more and more companies are using specialized groups who not only study materials and methods, recommend changes, and finally write operation sheets on new products but also are constantly alert for changes which will improve or reduce cost of old products.

Design engineers and research workers in general realize that production problems often involve changes in original drawings or specifications. When wholehearted cooperation exists between the people

presenting the original theory and those working with the hard, cold facts of production costs, the result is a kind of teamwork which reduces production costs rapidly.

However, it would be difficult to have these production-minded people working for the design and research engineers at the initiation of a project for several reasons. If the process development or product analysis groups were working with or for the design or research engineers, there might be a tendency for one group to dominate. If the production group dominated at the time new designs or formulas were being developed, it might seriously hamper the creation of new and unique products by insisting on the use of existing production materials and facilities. On the other hand, an independent approach, with one group responsible for creation and the other for production, provides an adequate check and balance procedure.

CLASSIFICATION OF MATERIALS

After the process development or product analysis group has come to an agreement with the research or design engineers on the materials to be used, then production control, often in cooperation with cost accounting, must provide an inventory record as a starting point for controlling production in the shop.

For control purposes it is necessary to classify the materials in the plant. Materials used in the production of goods may be grouped according to one of two major classifications. The first of these is based on the state of completion in the plant.

1. Raw material.
2. Material in process.
3. Finished goods or materials.
4. Purchased finished materials.

Materials at any one stage of the manufacturing process should be definitely classified into one of these groups. Any error in the classification of materials affects the validity of financial statements which should include the inventory value of all materials.

Raw Materials. Raw material may be defined as the substance worked upon in the first operation for a part or product, that is, before any processing or fabricating has been done. Raw material for one plant, then, can be finished material from another plant. Wheat, the finished product of the farmer, is raw material for the flour mill, and the product of the flour mill is the raw material for the bakery. The finished product from the bakery may become one of the raw

materials for a concern putting up box lunches. In an integrated plant, pig and scrap iron, coke, and limestone are raw materials for the foundry, whereas the finished castings from the foundry department are materials in process when on their way to the machine shop. On the other hand, castings from an outside foundry not owned by the same concern are raw materials for the machine shop.

Process Materials. Material in process is the material in a partially completed condition of manufacture. This group of materials is to be found in the machines, on the conveyers, trucks, or other means of transportation, or in temporary storage places waiting to be assembled. Raw materials become process materials at the first process operation and remain in that classification until they become finished goods ready to ship.

Complications may arise from time to time, as when an integrated plant including a foundry and machine shop sells castings to another machine shop. The castings sold to the outside shop are finished goods rather than process goods to be delivered to the machine shop of the integrated company.

Finished Materials. Finished materials or goods are those products in a completely finished condition which have not been delivered to the customers. Materials usually leave the "in process" classification and become finished materials at the point of final inspection or when they are ready for delivery to the customer or finished stockroom.

Purchased Finished Materials. Purchased finished materials differ from goods or materials finished in the plant in that they require no processing before being used in the assembly of other products. Few concerns make their own nails, bolts, or screws, and even such a highly integrated plant as the Ford Motor Company buys carburetors, radiators, and other completed units. Many plants are largely assemblers of purchased finished units with only a minimum amount of processing operations actually done in the plant. Oil burners, radios, and electric refrigerators are assembled in this way by certain companies to avoid big investments in production equipment.

Finished units often can be purchased more cheaply than they can be made in one's own plant. Highly specialized labor and machinery can produce certain products much more cheaply than a general-purpose plant. The Corning Glass Works has machines producing the glass bulbs used for electric lights and radio tubes. These machines produce bulbs automatically at the rate of 450 to 500 per minute. No concern using only a small fraction of this production of bulbs per day can afford to make its own. Periodic studies should be made to check relative costs of materials when worked in the plant or when

purchased finished because conditions may change enough to justify a shift from one method to another.

Purchased finished materials reduce the work of the planning division for it is only necessary to requisition the materials through the purchasing department which in turn places the orders and sees that they are delivered on a date set by the planning department.

Direct and Indirect Materials. The second major classification of materials is based on the manner in which the material cost is charged to the final product. Material that can be charged to specific jobs, processes, or commodities is considered as direct material. Indirect material is that material which is general in character but which is difficult to assign to a given unit of product for the purpose of cost finding.

Examples of direct materials are the wool used to make blankets, steel to make a wheelbarrow, olive oil to make salad dressing, and glue to make kalsomine. All these are used in definite quantities in the products mentioned, and the amount in each unit of product can be measured. Indirect materials in some products may be identical with direct materials in another. They may be used in such small quantities or in such varying amounts per unit that accounting on a unit-of-product basis would be difficult. Under other circumstances the indirect material may be used only during manufacture and may be lost entirely or gradually as production progresses. An example of indirect materials is the special oil used just previous to the carding of wool in a blanket mill. The oil is atomized and allowed to mix in a continuous stream of wool going to the carding machines. The oil remains in the wool throughout the carding, spinning, and weaving operations to prevent the fibers from becoming brittle. During the washing operations on the blanket the oil is removed and is not recovered. Catalysts used in chemical manufacture are indirect materials which make many chemical processes possible, yet they do not enter the product. Nails, tacks, and screws are often charged as indirect materials because of the variable number used per unit. Glue used in a furniture factory is also usually charged to indirect material.

Supplies are those materials which aid production without actually entering into it. In some plants they are classified separately and in others they are considered as indirect materials. Such things as pencils and paper for office and shop use, brooms, rags, lubricating and cutting oils, and oils used for fuel and quenching in heat-treating plants are considered as either indirect materials or supplies.

From this discussion on direct and indirect materials, it may be seen that it is not always possible to classify a material into one or

the other group at the time of purchase. The general practice is to charge such purchased goods to the stores account and then charge each material to the proper direct or indirect material account when it is known how it is to be used on the job. Indirect materials and supplies are charged to the department overhead account.

EFFECT OF MATERIALS ON PRODUCTION

As stated before, materials provide the starting point for much of the thinking and all the work done in production. Often a part may be made from one of several materials. A gearwheel in a kitchen mixing machine can be made from a brass rod or casting with the teeth cut after machining the blank, or from a zinc die casting with the teeth cast. The camshaft in an automobile engine can be made of drop-forged steel or a special grade of cast iron with the cam sections cast in a chilled mold. The outside cover of a camera can be a plastic casting, a die casting, or a stamping. The frame for a large electric generator can be a casting or a welded section. These various materials are about equally acceptable to do the job the design calls for.

Since labor and material are the factors which comprise the prime cost of manufacture, the total cost of these factors determines to a large degree the material selected. Sometimes the more expensive material in cost per pound is actually cheaper in the finished product because of lower labor or overhead costs. At other times, the cheaper material may require expensive machines or processes involving large capital expenditures and high overhead charges. In either situation where fixed overhead costs are important factors, the volume of production may be the deciding factor in the selection of the material. On the other hand, when two materials involve practically the same labor and overhead costs per hour, the selection of material depends on the relative rates of production per hour rather than on the total volume of production.

Some processes, like die casting, are highly productive with little labor cost per unit; others such as welding may use more labor per unit produced while the saving lies in a lower material cost per pound. Rolled steel sections, used for welded fabrication, usually cost less than cast iron per pound. Moreover, because steel is stronger per unit area, less weight is needed in the finished product for the same strength. One can easily see that many variables must be considered in choosing the material to be used in any product. Formulas or economic balance calculations aid in the selection of the most economical material for

any current conditions. These calculations are explained on pages 87, 95, and 96.

The substitution of aluminum or brass for steel in bar stock screw machine work is a good example of different materials involving about the same labor and overhead cost. To a lesser degree the substitution of sheet nonferrous metals for sheet steel in certain punch press operations will show variations in cost which should be investigated. Inventory quantities or control methods are not changed to any great degree in these two examples. A projected change of die castings for sand castings, stampings for forgings, or any change involving the method of production is more complicated because more factors are involved. Return on additional investment, relative labor costs, setup costs, inventory costs, overhead costs, and different materials costs must all be considered to arrive at the proper answer.

Economics of Brass versus Steel in Screw Machine Work. In an article¹ by Sydney Fisher, formerly with the Bridgeport Brass Company, consideration is given to the problem where few changes in capital charges are involved. Some of the nonferrous metals such as copper, brass, and aluminum have certain physical properties which are desirable if their strength characteristics are satisfactory. Often they will take a higher natural finish, will require less work to produce a good nickel- or chromium-plated finish, and will resist corrosion under more severe conditions than will steel. When strength or magnetic qualities are not determining factors, the nonferrous metals should be carefully checked against steel to find which of the several materials is the cheapest to use.

The relatively higher cost per pound of the nonferrous materials is offset by the superior machining properties of most of them. The higher value of the scrap turnings per pound over steel scrap, and, for aluminum and other lighter metals and their alloys, the difference in density affect the calculations considerably. In practice these factors are balanced against the extra cost of machining steel and the added value of the nonferrous scrap over the steel scrap.

An important factor to consider is the higher value of the scrap metal produced in the machining process. Brass or aluminum scrap is worth a much higher percentage of the original cost than is steel scrap. Moreover, if the process is economical as far as the metal cost is concerned, there is the additional savings of floor space and overhead which comes from the greater production per hour. Owing to the increased output and the extra work of supplying more rod stock

¹ *American Machinist*, Vol. 62, p. 225.

and taking better care of the more valuable chips, the labor cost might be slightly higher per machine. This higher cost of labor is balanced by the longer life of tools, less tool sharpening, and consequently, less time lost in setting tools.

Cost Balance Sheet. It is easy to set up a balance sheet, similar to the one shown in Figure 1, showing the costs involved in using each material. Many problems of this type can be approached analytically

**BALANCE SHEET FOR SELECTING ONE OF SEVERAL MATERIALS WHICH
CAN BE USED FOR A GIVEN PART
(when processed on similar machines)**

	<i>Material A</i>	<i>Material B</i>
1. Cost per pound of raw material	\$0.04	\$0.15
2. Gross weight per piece (Do not neglect density differences.)		
3. Gross material cost per piece	0.25	0.27
4. Weight of scrap produced per piece (lb.)	0.01	0.0405
5. Value of scrap per pound	0.10	0.108
6. Recoverable scrap value per piece	0.005	0.09
7. Net material cost per piece (Item 3—Item 6)	0.0095	0.00972
8. Extra cost of more expensive metal per piece		0.03078
9. Labor cost per machine hour	0.02128	
10. Overhead cost per machine hour	0.30	
11. Output in pieces per hour per machine	1.10	
12. Machining cost $\left(\frac{\text{item 9} + \text{item 10}}{\text{item 11}} \right)$	41	X
	0.03415	1.40
13. To break even item 8 must equal item 12A — item 12B		item 11B
or	$0.02128 = 0.03415 - \frac{1.40}{X}$	

$$X = 109 \text{ pieces}$$

per hour per machine must be made to break even if material *B* is used.

FIGURE 1

by this method. Equations also can easily be developed to do the same thing, but unless they are carefully used and fully understood the method of balanced costs produces fewer mistakes and a better understanding of the problem.

As an example to be worked out in Figure 1, a designer finds it possible to substitute brass for steel as a material for a certain screw if the difference in cost is not too great. The present screw is made in an automatic screw machine from steel bar stock costing 4 cents per pound. Suitable brass bar stock would cost 15 cents per pound. Scrap value of the turnings are respectively $\frac{1}{2}$ cent and 9 cents per pound. Labor is paid 90 cents per hour and each man runs three machines. The overhead charge per machine hour has been \$1.10.

The screw made from steel requires $\frac{1}{4}$ pound of material, although the brass requires slightly more owing to greater density (1.08). Forty per cent of the gross weight is reduced to chips. The output in steel is 41 pieces per hour. How many pieces must be machined from brass per hour to break even with the steel cost?

For any production over 109 pieces per hour in the example worked out in Figure 1, there will be a saving in final prime cost even if the proposed material B does cost almost four times as much per pound.

In solving any current problem, it is important to obtain current prices for the several metals in bar form and the market prices for the corresponding scrap metals. Industrial centers usually have metal warehouses and scrap dealers who will quote local prices of various materials. Current prices for materials also may be obtained direct from the purchasing department.

General Consideration of Fact Relationships. A few generalizations, based on the expressions in Figure 1, may help to show the effect of the variables on the final result.

1. The higher the percentage of scrap turnings to the gross weight of any piece, the less difference in the extra cost of the more expensive material, provided, of course, that the scrap value of the more expensive material is also high.

2. As the gross weight goes down the extra metal cost per piece becomes lower.

3. When either or both of the labor and overhead rates per hour are high, the extra machining cost for the cheaper material A is greater. This has the effect of reducing the number of pieces per hour necessary to have the higher cost material B break even with the cheaper material.

4. When the nature of the machining is such as to require a longer time, the extra machining cost for the cheaper material A becomes larger in proportion.

5. Thus, to have the savings in cost of machining greater than the extra cost of metal, the following conditions are favorable: (a) when labor and overhead rates are high, (b) when machining processes are difficult and time-consuming, (c) when gross weight per piece is small, (d) when scrap turnings or waste are a high percentage of gross weight.

When ferrous metals are machined, the free-cutting materials are generally those with low strength and low Brinell readings. The high strength, high Brinell steels and irons are usually not free-cutting. In brass this same relationship does not always hold. The most important factor in determining free-cutting properties of brass is the lead content. The optimum percentage of lead for free-cutting is

about 3 per cent. If brass rods are hard drawn they still will be free-cutting if the lead content is high enough.

Recently, lead has also been added to certain steels to be used for bar screw machine work. The addition of lead to steel² has tended to make it machine more easily and this metal should be investigated along with others when cost comparisons of this nature are made.

Examples of Cost Comparisons. Part one in Figure 2 shows a 9 per cent increase in cost when the same part is made from steel. In addi-

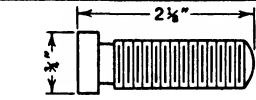
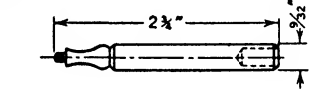

	Stock	Pieces per Hour	Cost Each				%	Mach. Prod.
			Mach. Time	Man Time	Stock	Total		
 #1	Brass	115	0.0087	0.0022	0.0434	0.0543	100	4.3
	Steel	27	0.0374	0.0078	0.0141	0.0593	109	1
 #2	Brass	160	0.0063	0.0016	0.0078	0.0157	100	2.2
	Steel	115 200	0.0087 0.005	0.0022 0.0025	0.0025	0.0209	133	1
 #3	Brass	200	0.005	0.0013	0.074	0.0803	153	4.5
	Steel	45	0.0225	0.0056	0.0243	0.0524	100	1

FIGURE 2. Total cost comparison between brass and steel.

tion the machine can make more than four times as many pieces per hour, or, in other words, only about one-fourth as much machinery is necessary to turn out the same number of parts.

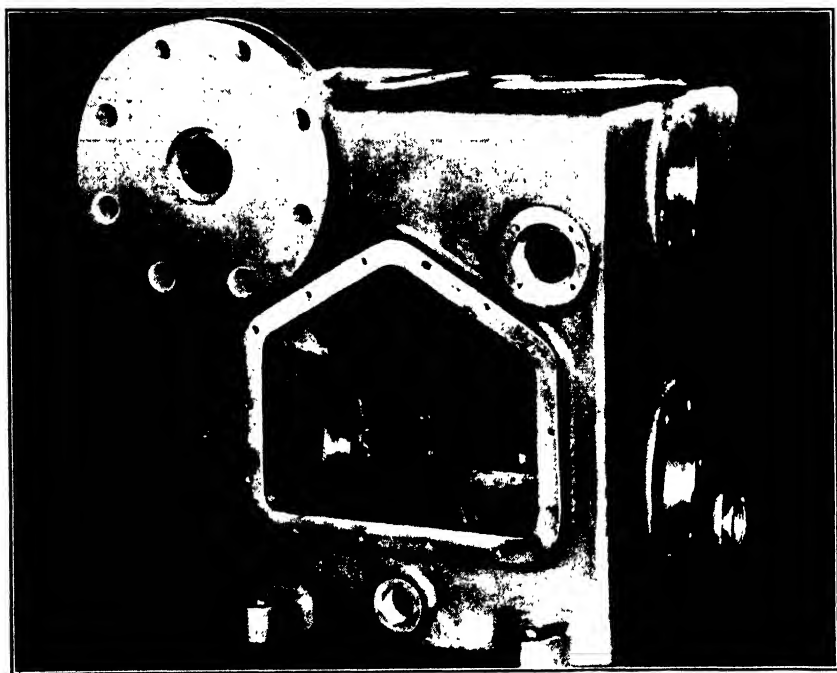
Part two in the same figure shows considerable saving because the piece is machined complete in one operation when it is made of brass. This is done by rolling the thread and skiving the back end. Neither the skiving nor rolling of the thread would be practical if the piece were made from steel because the pressure exerted by the tools would be sufficient to bend the piece. Two operations would be necessary to complete the work if steel were used. When this is taken into consideration steel costs 33 per cent more than brass.

In part three, even though four and one-half times as many pieces are made in brass, the excess metal cost is too great to be overcome by savings in machine cost. This, however, is a case where the plumb bob would be made of brass, regardless of cost, because of its re-

² *Manual on Cutting of Metals*, American Society of Mechanical Engineers, 1939.

sistance to corrosion. Thus, it is pleasant to know that the added cost of the brass for this part is nowhere near the amount the difference that the raw material would indicate.

Cost Balance Where Several Variables Are Present. Not all material changes are so easy to calculate as those in which the different materials can be handled by the same type of machines. Quite often it is



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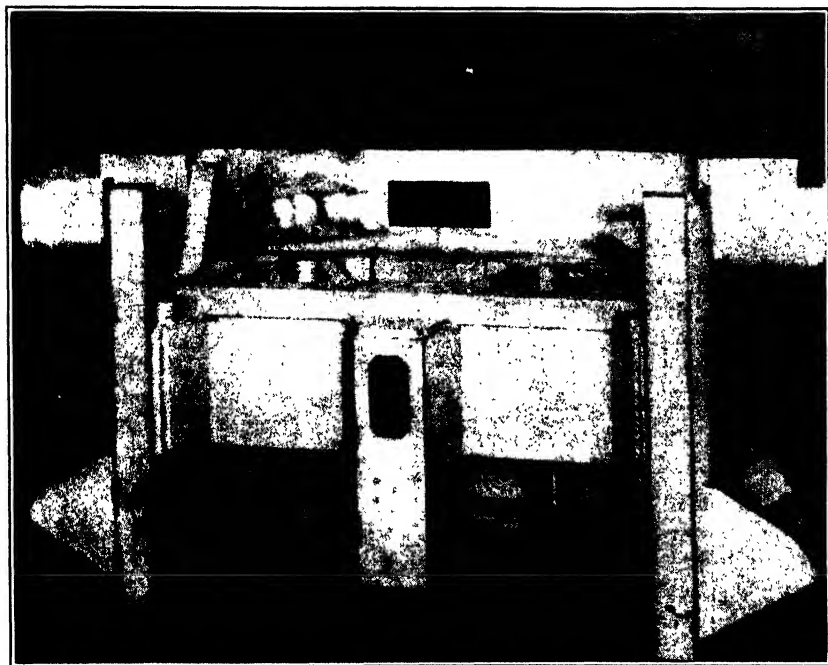
FIGURE 3. Welded machine housing, weighing 200 pounds. Note thick and thin sections and round corners.

necessary to change the design to accommodate the new materials. The use of high-strength, long-lasting rayon cords in modern tires resulted in changed specifications for the tread rubber to enable it to wear longer. This change in turn called for a change in the tread design. New tools, new molds, new machines, and new equipment often are necessary when materials are changed.

A change from die castings to plastics or vice versa requires a complete change of machines. When welded fabrication is substituted for foundry castings of iron or steel, a complete change is required not only of machines but of work places and working conditions. Molders and patternmakers are not needed for welded sections. Steel rolling

mills furnish the raw material instead of foundries. Changes can be made in material which seem simple enough on first thought, but sometimes the economic ramifications are far from simple. The steel in steel castings and drop forgings may have almost identical specifications, but the methods of producing them are widely different.

Welding versus Casting. The early welded fabrications were severely criticized for their angular, ungainly appearance. Customers did not



Lincoln Electric Co.

FIGURE 4. Welded broaching machine table.

take kindly to the straight lines, square corners, and sharp angles which were so common in the early designs.

Today, products are manufactured from steel plates and other rolled steel sections which are as pleasing in line and form as those produced by other methods. In fact, when a modern machine of welded construction has several coats of paint, it is difficult to tell whether the parts have been welded or made by more conventional methods. Thus one of the economic difficulties, that of sales resistance due to appearance, has been removed.

Figure 3 shows a housing weighing 200 pounds, which was produced by the shielded-arc process. It has smooth lines and it has the ap-

pearance which only castings had a few years ago. The housing was made of $\frac{1}{4}$ -inch plate with the bosses varying from $1\frac{1}{8}$ to $2\frac{1}{2}$ inches in thickness. Naturally it is quite a problem to cast such a housing with thin sections on the side in which are also incorporated extremely heavy bosses.

The table for a broaching machine shown in Figure 4 is an example of a welded product which would be difficult and expensive to produce

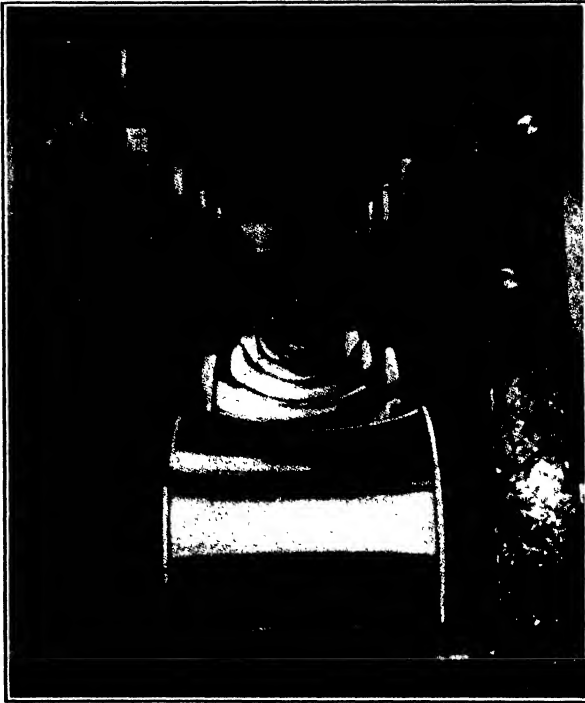


FIGURE 5. View of bottom row of forming rolls, the upper roll housings having been removed at the time this photograph was taken.

in small lots by conventional methods. Note the difference in the thickness of the various sections. This was always a problem until welded construction made it easy. The advantages in fabricating this table from plate lie in the different types of worktable required, for almost every table is different in some respect from previous ones built.

Because of its advantage in manufacturing processes, steel plate cut by the oxyacetylene torch and welded together electrically is receiving more and more attention from engineers and designers.

The mathematical analysis for situations where machinery, processes, material, and factory procedures are changed, involves more

entries on the balance sheet, but the method is essentially the same as the one used in Figure 1.

The demand for certain materials often forces a change in the method of production in order to lower the cost and improve the quality.

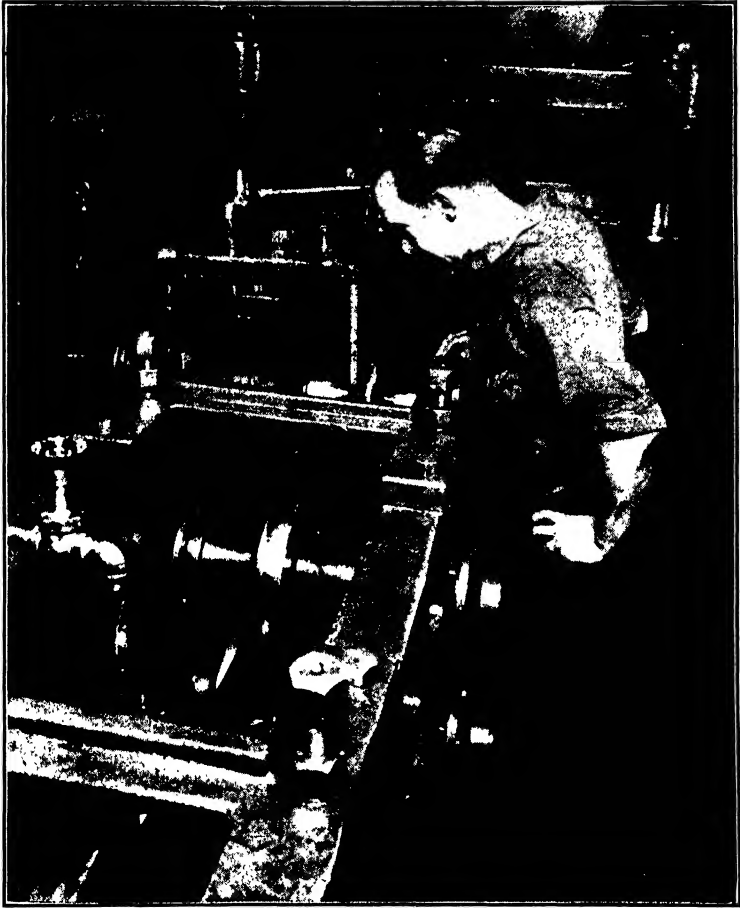


FIGURE 6. Note contour of top rolls.

Welded steel tubing³ has been in use for many years, but the methods by which it is made today differ considerably from the early processes. The use of welded steel tubing was greatly stimulated by the large-scale manufacture of bicycles, and the bicycle industry is

³ "Steel Tubing Made by Resistance Welding," Charles O. Herb, *Machinery*, Vol. 44, No. 1, p. 3.

still an important consumer. When the automobile and airplane industries became large users of welded steel tubing, their rigid demands for quality led to the improved manufacturing methods now in use.

In the tube-forming process, the flat stock is first fed through rolls which gradually shape it to the form of a circle. Then the butted edges are welded together to make a continuous tube. Tubes up to 16 inches in diameter, with a wall thickness of $\frac{1}{2}$ inch, are made by the same method. The strip stock is received in coils from the steel mill and trimmed accurately to the width necessary for shaping to the required diameter. The stock first passes through a pair of driving rolls and then through a series of forming rolls that produce the tubular cross section. As each coil of stock is used up, the end is welded to a new coil so that the feed is continuous.

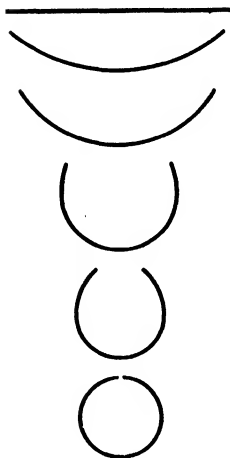


FIGURE 7. Diagrams illustrating the successive steps taken in transforming flat stock into tubing.

At the beginning of the operation, the bottom rolls are shaped as illustrated in Figure 5 and the top rolls are just the opposite, as shown in Figure 6. However, the final forming rolls are of the same contour, top and bottom. In passing through this series of rolls, the stock is curved gradually in the manner illustrated diagrammatically in Figure 7 until a concentric tubular shape is obtained. When the tubing leaves these rolls, there is space of about $\frac{1}{16}$ inch between the butting edges.

The butted tubing is now drawn through the welding section of the machine illustrated in Figure 8. As the formed tubing approaches the welding unit, it is guided in line with the electrodes by a steel blade which enters into the space between the unwelded edges. When the tubing passes under the electrodes, current is automatically applied, traveling from one electrode to the other across the tubing, creating heat through the resistance offered to the flow of the current. At the moment that the current is applied, the side rolls *B*, Figure 8, exert sufficient pressure to bring the heated edges together and form a welded joint. A second pair of rolls, similar to rolls *B*, supports the welded tubing at the sides after it leaves the electrodes. Directly below the electrodes, the tubing is also supported by a pressure roll *A*.

Various tests are performed to make certain that the tubing has the required physical properties. For instance, the specimen in the middle of Figure 9 has been expanded outwardly at one end by means

of rolls and flanged back, without tearing or cracking the tube at any point. The example at the left has been crushed endwise without fracture, and the specimen at the right has been flattened sideways.

Drop Forging versus Steel Casting Analysis. The change from the use of a steel casting to a drop forging usually involves some engineering changes. These two methods of producing parts in steel differ so

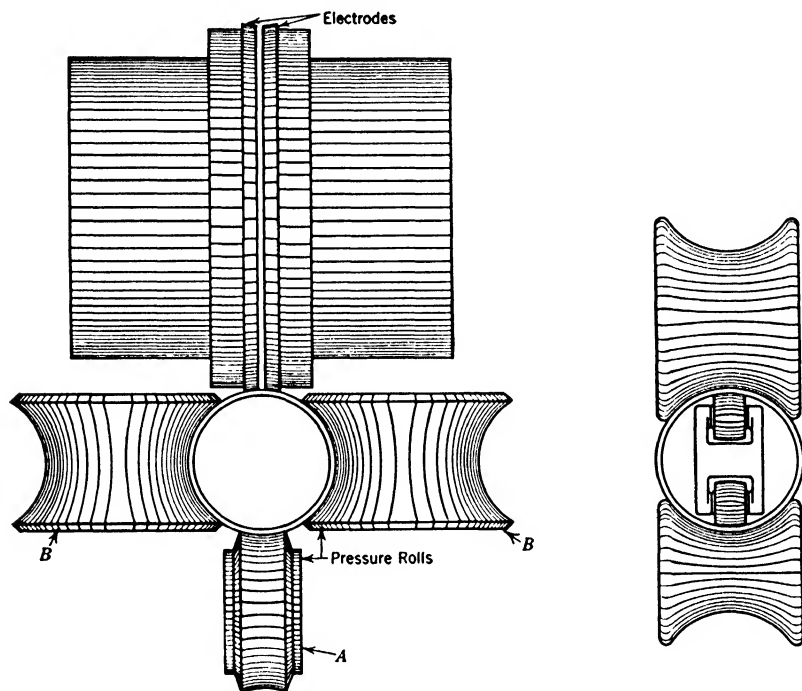


FIGURE 8. Diagrams illustrating the application of rolls on both sides and beneath the electrodes that force the heated tube edges together to form a weld. The view at the right shows the method of applying planishing rolls for smoothing down the weld flash.

widely that slight changes may be necessary in the original design of the piece. Since draft allowances are in different places, and since drop forging requires seven degrees instead of the one or two degrees needed in foundry castings, the holding fixtures, jigs, and other machining equipment may need certain changes.

Moreover, the adoption of drop forgings would involve the design and manufacture of the necessary forging and trimming dies. At times, owing to low production, the expenditures for new tooling and necessary changes in old tools and jigs cannot be justified, even though forgings cost considerably less than steel castings on a pound basis.

When the product has been developed sufficiently to have a stable demand, or when it is no longer necessary to change design frequently, the use of drop forgings may be more economical than steel castings.

When forgings are used, they generally are made in rather large lots, because of high setup costs and the large number of pieces forged per hour. Whenever parts are made faster on one operation than on another, it becomes necessary to store temporarily the output of the

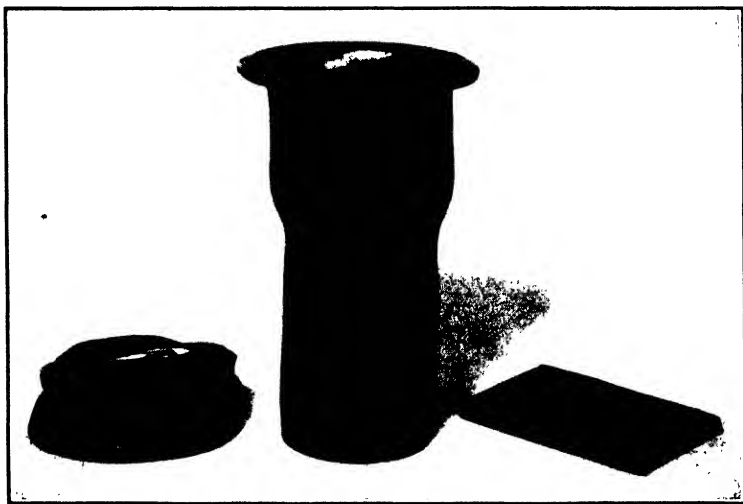


FIGURE 9. Physical tests for weld quality.

first operation. This storage function involves an additional expense for interest, taxes, and storage charges which usually are higher for forgings than for castings.

The difference in cost between steel castings and steel drop forgings is a question of balancing the various costs incurred with each material. Due consideration must be given to the effect that quantity has on these costs.

The cost of engineering changes should be spread over the number of pieces which are to be made with the new changes. This will sometimes require an estimate. For conservative action the costs of tools should not be spread over more than a one- or two-year period. For products of a novelty nature, the engineering costs should be charged off as quickly as possible. Careful judgment is necessary in estimating how many units of the product should be used to absorb the engineering charges. If serious mistakes are made in the distribution of costs to each unit, the final results also contain mistakes and the economic action taken may be wrong.

Machining operations are about the same whether forgings or castings are used. In some material substitutions machining operations and costs are quite different, which, of course, should be taken into consideration in the final selection of the material.

Formulas⁴ have been developed to calculate the production rate which is necessary for a new material to compete economically with an older material. Generally, however, formulas must be constructed to deal with a specific problem. For a more general application, which allows the inclusion of different costs as they are encountered in a specific case, the "balancing of cost" method illustrated in Figure 10 is recommended.

In the economic balance sheet shown in Figure 10, all pertinent costs for each material are listed and added together algebraically to show where the break-even point lies. Some of the costs cannot be expressed directly in dollars; they must be expressed as a function of N , which is the number of pieces which must be made per year in order to have the cost of the suggested new material break even with the cost of the old material.

For instance, interest, insurance, and taxes are based on the length of time it takes to use up an ordered quantity of parts made from any of the several materials. If N pieces are to be made during the year, then the annual cost of interest, insurance, and taxes as derived above can be divided by N to get the cost per piece.

N thus represents the unknown number of pieces needed to break even. N appears in Figure 10 whenever the unit cost is desired and the total or annual cost is known.

Any extra costs such as additional machinery required for a new material can be placed as a charge per piece based on the ordinary capital and operating costs for the machine and the number of pieces to be run during the considered time. Each extra cost should be calculated on a per piece basis and included for the final analysis in the additional items 17 and 18 in Figure 10.

Problem Worked as an Example in Figure 10. The statement of the problem analyzed in Figure 10 is as follows:

The gross weight of a steel casting is 7 pounds. The gross weight of a drop forging to replace it is 8 pounds. The finished net weight of the part is 6 pounds after all machining is completed. Steel castings of this type cost 15 cents per pound though drop forgings to replace them cost only 6 cents per pound. The steel scrap turnings are

⁴ *Economic Control of Engineering and Manufacturing*, F. L. Eidmann, McGraw-Hill Book Co., 1931, pp. 88-89.

**BALANCE SHEET FOR SELECTING ONE OF SEVERAL MATERIALS WHICH
CAN BE USED FOR A GIVEN PART**
(when processed by different machines and methods which involve
different combinations of cost)

Part Number	3041	Part Name	Gear		
		Mat. A.	Drop Forging	Mat. B.	Steel Casting
		Mat. A.		Mat. B.	
1.	Cost per pound for piece ready to machine (Does not include item 9)	\$0.06		\$0.15	
2.	Gross weight per piece (lb.)	8		7	
3.	Gross material cost per piece	0.48		1.05	
4.	Weight of scrap produced per piece when machined (lb.)	2		1	
5.	Value of scrap turnings per pound	0.005		0.005	
6.	Recoverable value of scrap from each piece	0.01		0.005	
7.	Net cost of material per piece (item 3 - item 6)	0.47		1.045	
8.	Number of pieces produced per year		N		
9.	Cost of engineering changes to use new or suggested material		615.00		
10.	Engineering charges to be amortized in		2 years		
11.	Cost of engineering charges per piece ($\frac{\text{item 9}}{\text{item 10} \times \text{item 8}}$)	$\frac{615.00}{2N}$		0	
12.	Number of pieces ordered per purchase or manufacturing order	600		25	
13.	Annual storage charge based on <i>max. or av.</i> demand for space to store (item 12) @ \$0.01 per piece per year	6.00		0.25	
14.	Annual storage charge per piece produced per year $\frac{\text{item 13}}{\text{item 8}}$	$\frac{6.00}{N}$		$\frac{0.25}{N}$	
15.	Annual interest, insurance and taxes @ 7 % on average stock carried $\left(0.07 \times \text{item 7} \times \frac{\text{item 12}}{2}\right)$	9.87		0.91	
16.	Annual interest, insurance, and taxes per piece produced per year	$\frac{9.87}{N}$		$\frac{0.91}{N}$	
17.	} Any other pertinent unit costs (such as extra machining costs)				
18.					
19.	Total costs per piece (sum of items 7, 11, 14, 16, 17, 18)	$0.47 + \frac{323.37}{N}$		$1.045 + \frac{1.16}{N}$	
20.	Break-even point occurs where total costs for both materials are equal (item 19A = item 19B) or $0.47 + \frac{323.37}{N} = 1.045 + \frac{1.16}{N}$				
	N = minimum number of pieces to be produced per year to make material A break even with material B. If more pieces are produced, the use of material A will show a profit.		560 Pieces		
21.	Number of pieces to amortize engineering costs spread over 2 years =		1,120 Pieces		

FIGURE 10

worth \$10 per ton. The adoption of drop forgings will mean an outlay of \$615 for tools, dies, and other engineering charges. This expense must be recovered in two years. Drop forgings must be ordered in lots of 600 pieces in order to get the 6-cent price. Castings can be ordered in lots of 25 pieces. Interest, insurance, and taxes combined are 7 per cent of the average stock on hand. Storage charge is 1 cent per year per piece. How many forgings must be made during the estimated economic life of the proposed tools and equipment to break even with the cost of the same number of castings?

Basis for Storage Charges. Frequently, storage charges can be based on the space required by the average number of pieces on hand, but sometimes the space required for the maximum number of pieces on hand must be used as a basis of cost because the space relinquished by the stock being gradually removed is not always available for other material. When a new order is received, the stock again becomes a maximum, and, if the space is not available to store it, something must be moved to make room for new incoming stock. Since it usually costs more in labor and damage to move this stock from one place to another, it may be cheaper to set aside space for the maximum quantity to be stored rather than the average.

Storage space and the charge per year per part stored is calculated to find the charge per square foot of net storage space. That is, all space used for aisles, desks, stairways, elevator loading, and unloading in the storeroom is not classed as storage space. The total cost of maintaining space, including all the items of heat, light, rent, and janitor service, is divided by the number of square feet used for actual storage in bins, boxes, and piles. This charge per square foot includes all space from floor to practical storage height. If a part is stored in one of four bins, each 2 feet high over all, then the space chargeable to that part is only one-quarter of the floor area of the bin. The practical height for storing fifty-two gallon barrels of oil is only the height of one barrel. However, if tiering trucks are used, this practical height is restricted only by the ceiling or the floor-loading limit, whichever one comes first.

Materials are an important part of the prime cost in most industries. Their importance justifies further discussion and analysis in Chapters VII and XIX and in parts of Chapters IX and XII.

QUESTIONS FOR DISCUSSION AND PROBLEMS

Sufficient data is given for each problem, but the student must exercise his ingenuity to use this data for solving the problem.

100 MATERIALS, THEIR CLASSIFICATION AND SELECTION

1. In a large commercial bakery, what are the most important properties the baker must consider when he selects materials to develop a new type of bread?

2. Assume that this large bakery, in Problem 1, has an industrial engineer. What problems do the materials used in a bread bakery present from a materials handling, processing, storing, aging, and sanitary standpoint?

3. Name, discuss, and classify all the materials used in a furniture factory which makes only school classroom chairs. Assume that a physical inventory is being made and all material must be classified.

4. A firm would like to use a brass, hexagonal, standard, national fine series thread $\frac{5}{16}$ -inch brass nut if the added cost over a steel nut is not more than 5 per cent. These nuts are to be made on an automatic screw machine which costs \$0.30 for labor and \$1.00 for overhead per hour. Production is 150 pieces per hour for steel. Use current local metal and scrap prices. Is it feasible to use the brass nut?

5. The gross weight of a part made from steel is 0.3 pound. The $\frac{3}{4}$ -inch bar is turned in an automatic screw machine with a loss in weight of 35 per cent. The steel parts have been produced at the rate of 45 pieces per hour. In a campaign to lighten the product which contains ten of the above units, the designing engineers have decided that aluminum or Dow metal can be used for this piece if the prime cost for the ten pieces is not increased over 10 per cent. Labor cost per machine hour is \$0.35. Overhead cost per machine hour is \$1.25. Use current local district metal and scrap prices. Is the weight reduction program within the economic limits set?

6. The gross weight of a steel casting is 10 pounds. The gross weight of a drop forging to replace this steel casting is 11.5 pounds. The net weight of the finished part before it becomes a part of any subassembly is 7.5 pounds. Local steel foundries have been furnishing the steel casting for \$0.145 per pound delivered but with the right to buy all the steel scrap and turnings at \$6.00 per ton. Drop forgings have been offered as a substitute for the steel casting at a conditional price of \$0.05 per pound f.o.b. Forgingtown, with a \$0.35 per 100 pounds freight added to get the forging to the machine shop. In addition, the scrap and turnings are now subject to market price. The local steel foundry will use them if it can buy for \$6.00 per ton. The market price at the nearest steel mills is \$10 per ton delivered, and the freight rate is \$2.50 per ton to the mills. To use forgings in the plant, it is necessary to make changes in jigs, fixtures, and drawings which will cost \$325. Since the forgings are a part of a product which has annual model changes, these charges must be absorbed in one year to be conservative. Forgings must be ordered in lots of 600 to get the \$0.05 per pound price. If 200 pieces are ordered per lot, the price becomes \$0.055 per pound. Castings can be ordered from the foundry as needed with twenty-four hours' notice. Annual rate of interest, insurance, and taxes is 8 per cent. Annual storage charge per forging is \$0.0125. Can forgings be justified if 1,000 units are to be made during the next year?

7. What type of materials can tend to have their storage charges based on the average amount of stock on hand? What type of materials are stored in such a manner as to make it expensive, if not impossible, to reduce the storage space as the product is gradually used?

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CHAPTER VII

ORDERING, RECEIVING, STORING, AND ISSUING MATERIALS

An absolute necessity in production control is to have all materials on hand when they are needed. The lack of $\frac{1}{4}$ -inch nuts on an automobile assembly line will hold up production just as much as will the lack of engines or bodies. It would be desirable, although it is seldom possible, to have everything arrive in just the right quantity and quality on the day it is needed for fabrication. Since such ideal conditions occur only in a theoretical paradise, it is necessary to carry stores of various materials to provide a bank for emergencies.

Purchasing and Production Control. Most progressive manufacturing companies have a central buying department with full and complete authority for acquiring all supplies and materials used by the company. The purchasing department must necessarily be in close contact with the manufacturing division, but it is seldom subordinate to it. In some small plants, the buying is often done by the treasurer or some other regular officer of the company, but it is not considered good practice to make more than one man responsible for the actual purchasing.

Production control usually determines the quantity of production material needed and fixes the schedule for its delivery. The information concerning the need for materials may come from several sources; however, the usual and most reliable source is the inventory control record (see Chapter XIX). This record attempts to control the quantity of any part or material within certain limits to reduce excessive inventory charges on one hand and shortages on the other. There are several methods of inventory control in current use depending on manufacturing conditions, but, regardless of the method, a purchase requisition (Figure 19 in Chapter XVIII, and Figure 1 of this chapter illustrate two types) is prepared by production control for the purchasing department when additional materials for production are to be brought into the plant. This requisition must be released to allow the full purchasing lead time necessary for orderly purchases. When production control causes too many emergency purchases, the

excess cost of such purchases is a legitimate charge against the production control department account.

Information for Purchasing. It has been said "No man's judgement is better than his information." Buyers need as complete information as possible on all factors affecting the production, quality, and cost of any materials to be used. This information often is determined by design engineering or by the specification writer. If the drawings and other engineering data sheets do not give complete information,

UNITED STATES AIR CONDITIONING CORPORATION REQUISITION ON PURCHASING DEPARTMENT			
FORM NO. 1			
REQUISITION NO. _____		PURCHASE ORDER NO. ASSIGNED _____	
DATE OF REQUISITION _____		DATE NEEDED _____	
PLEASE PURCHASE THE FOLLOWING ITEM			
PRODUCTION ITEMS ONLY		(GIVE COMPLETE SPECIFICATIONS)	
QUANTITY	PART NO	MATERIAL NO	DESCRIPTION
SUGGESTED VENDORS _____		DELIVER TO _____	
		FOR ACCOUNT NO. _____	
		AUTHORIZED SIGNATURE _____	

FIGURE 1. Purchase requisition for a single item.

it should be supplied as soon as possible. The following information should be complete and clearly stated on all requisitions:

1. Accurate specifications and descriptions of what is wanted.
2. Actual quantities needed during a stated period and a schedule of deliveries if partial shipments are desirable.
 - 2.1 Factory schedules are usually based on these delivery dates, so they should be truthfully stated by production control and carefully followed by purchasing.
3. Name of department or stockroom where material is to be used or stored.
 - 3.1 This is for the benefit of the receiving group so that they will know where to deliver the goods when it arrives.
4. A list, if possible, of acceptable and reliable vendors, especially if the requisition is for an unusual purchase.

The purchasing department should have permanent records to show the following facts regarding the items regularly purchased:

1. A record showing the past history of all former purchases for each regular item to provide a guide for future action.
 - 1.1 If possible, the vendor's production cost of each item should be on record so that the buyer will know values.
 - 1.2 The normal spread between production cost and price of the class of goods should be on record to aid the buyer in making intelligent purchases.
 - 1.3 The record of each vendor should be kept on his delivery promises for past orders.
 - 1.31 This is important when inventories are carefully controlled to avoid disappointments in deliveries.

Since conditions are constantly changing, care is necessary to keep the purchasing information up to date. The purchasing record should be posted for each purchase. Trade publications, trade associations, statistical services, government agencies, and vendor's agents are all useful sources of live information for the files. Statistical and catalogued information, however, is useful only as an additional tool for the use of skilled, experienced buyers.

Growth of Centralized Purchasing. Modern purchasing is the outgrowth of a system under which clever trading and often sharp practices were considered desirable. The purchasing agent was a man for the vendor's agent to circumvent by means fair or foul. Elbert Hubbard once satirized the system by saying, "The typical buyer is a man past middle life, spare, wrinkled, intelligent, cold, passive, noncommittal, with eyes like a codfish, polite in contact, but, at the same time, unresponsive, cool, calm, and damnably composed as a concrete post or a plaster of Paris cat; a human petrification with a heart of feldspar and without charm; or the friendly germ, minus bowels, passions, or a sense of humor. Happily they never reproduce, and all of them finally go to Hell."

Fortunately for business and the pleasure there is in it, industry today has developed purchasing organizations, which, instead of injuring business by unfair and sharp practices, are making a conscientious effort to build good will and good business by mutual consideration and fair practices.

Purchasing by Specification. Modern purchasing is concerned with merchandise that has been carefully specified. To be of any value, specifications must be complete, unambiguous, and accompanied by drawings or other pictorial matter when necessary. If the requirements are technical, they are prescribed and drawn up by the engineers or other scientific men responsible for the product's performance. Sometimes national societies such as the American Society of

Mechanical Engineers, American Chemical Society, American Standards Association, or others, may have standard specifications for materials such as boiler steel or a chemical's purity. There are also design standards. If special equipment or tools are needed, complete drawings may accompany the purchase requisition, and usually a standard performance in service tests is required before the goods are accepted and paid for.

Some materials are difficult to buy by specifications alone. If the purchaser assumes that his specifications are complete and the materials or goods perform unsatisfactorily in service, the vendor is not responsible if the original specifications have been met. Such materials as lubricating oil, cutting compounds, heat-treating compounds, soaps, paints, tool steel, boiler compounds, sweeping compounds, coal, leather, and many others are difficult to describe by words or pictures. Sometimes even the best-known specifications for some materials fail to insure satisfactory performance of the material. Since satisfactory performance is the ultimate requirement of any industrial material, it is sometimes unwise to rely on written physical specifications only. Often the requirement of performance tests and records in addition to written specifications would provide better materials for particular uses.

Low Price Is Only One Factor in Good Purchasing. It is not enough to consider only the purchase of raw material for delivery to the stockroom. Whenever any manufacturing operations are to be performed on a material, the final cost must include all additional expense incurred by needless work expended to make a cheap material usable. Castings with hard spots and blow holes in them often can be purchased for less than sound, soft castings from a good reliable foundry, but extra machining costs, lost time, and scrap expense will more than offset any apparent saving in the purchasing department. A foundry superintendent ordered some asbestos board plates of a particular kind made especially for core oven plates. The purchasing department made an apparent saving over the estimated price by ordering an ordinary asbestos board which warped badly after several batches of cores were baked on them. The apparent saving became a loss because the material originally called for was finally purchased to provide a satisfactory core plate. The cost of material, supplies, tools, or equipment must be calculated by considering all costs involved in their use for producing a satisfactory final product.

Purchase Followup. The purchasing department is not only responsible for placing orders at the lowest possible price consistent with decent consideration of their vendors and final cost of product, but

the material must arrive not too long before and certainly not after a fixed date. Since this phase of the purchasing problem is intimately connected with the inventory control, it can seriously upset a planned system if not properly conducted. Consequently, a followup system is often used where purchasing is controlled by high turnover methods. The followup system varies from a simple tickler file where vendor's promises and deliveries are checked shortly before they are due to arrive, to an elaborate checkup on all phases of the vendor's activities in getting ready to deliver the order. In the most elaborate systems, the vendor is asked to notify the followup section: (1) when the order is received; (2) when (if it has to be manufactured) the order enters the shop, and, in some cases, when it has completed certain phases of its manufacturing cycle; and (3) when it is shipped. In addition, shipping data should include the quantity, the car number, and train, or it should indicate whether the goods were shipped by other means of transportation. If everything goes closely according to a prearranged schedule, the followup system has little to do except watch incoming reports from vendors, but, if trouble develops in fulfilling this schedule at any point, immediate action is necessary to prevent shutting down some portion of the plant. This highly coordinated attempt to keep inventories down to a bare minimum sometimes looks foolish to the old-style plant management with many months' supply of all materials safely on hand for any emergency. When a car of materials which is due the next morning to supply operations for that day develops a serious hot box during its trip to the plant, it may be dropped off at a convenient siding; the followup section is notified and a man may be dispatched with a company truck to the location of the delayed car to get sufficient material to carry the operation until the supply becomes regular again.

Naturally, the law of diminishing returns can set in quite severely here unless the economic results (in less inventory) are critically checked with the costs over a period of time with this technique.

Expense of Delayed Materials. Delayed material may cause considerable extra expense for fast transportation of heavy goods; for overtime work on parts when they finally do arrive in the shop; and for process inventory costs on those parts already in the shop and waiting for the delayed material. Promised delivery dates are broken and, even if the customer can be persuaded not to cancel the order, the finished part may have to be shipped by the fastest method, the extra cost of which is borne by the producer. Good production control will prevent most of this difficulty and also at the same time will eliminate an unnecessarily large investment in inventory.

Minimum Cost—Purchase Quantity. It is beyond the scope of this book to discuss the details necessary for routine operation of a purchasing department. We are more interested here in techniques and economic considerations to determine the proper quality and quantity of material to give the lowest over-all cost of the finished goods.

Before placing an order, a purchasing agent must consider not only price but quality, delivery date, and quantity to be delivered. If the order is delivered too late or if the quantity is too large so that storage, interest, depreciation, and obsolescence charges increase the unit cost, the purchasing department is not doing a good job. On the other hand, if too small a quantity is purchased, the procurement charge will increase the unit cost. The purchasing department must steer a course between extremes where judgment and experience can often be aided by a mathematical treatment of the quantity to be bought. This problem is difficult to handle by the balance sheet method. It is far easier to develop the formulas by calculus and use the simple equations thus developed. Where the style element is of little importance, the material often is more or less standard. The work of the purchasing department consists largely of replenishing stores by means of reorders. Here, one of the main problems is how much to order. If the quantity is set by haphazard methods, there is no guarantee that the minimum cost per unit has been achieved.

INVENTORY RELATIONSHIPS FOR PURCHASED MATERIALS

Figure 2 shows the relationship between the order point O , the point C where serious expediting must be done if the order has not been received, and the average use line AB . These relationships are shown theoretically for a logical approach to the problem, with the minimum of variables.

The stock O is theoretically used during the lead time. However, since the procurement period of the lead time may not always be consistent with all materials, it is necessary to carry a reserve stock R which is a function of the quantity O_1 (or see below).

Minimum and Order Point Stock Levels. When the actual physical stock on hand or the stock available for future orders¹ falls to a predetermined level O , a purchase requisition is originated in production control. The amount of stock on hand at point O depends on the lead time and the rate of consumption. Expressed mathematically it is $O = TU$, where T is in years.

¹ Depending on the method of inventory control used (see Chapter XIX).

The reserve stock R can be expressed as a function of the stock quantity O which is used during the lead time; in some plants, R may be expressed as one or several normal weeks' supply. Thus R may vary from 10 per cent to 200 per cent or more of the stock O , depending on how consistent the procurement time is for the particular material. The most practical method of determining the reserve stock quantity is to have the stockroom report the amount of stock on hand

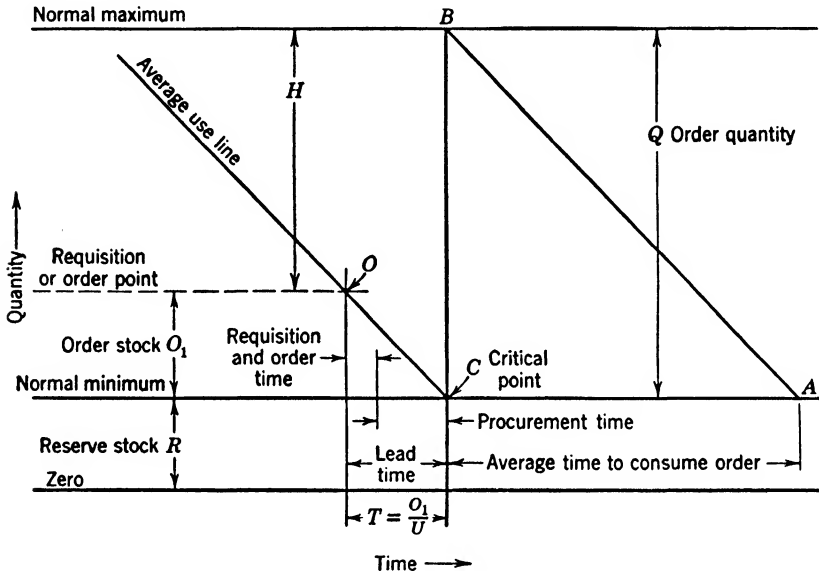


FIGURE 2. Theoretical relationships between the variables that affect purchasing.

when the purchased quantities are received. If the reserve is gone or dangerously low, it should be increased. On the other hand, if the reserve is considerable when the new shipment arrives, it can be reduced. Care must be exercised to keep the reserve as low as possible to prevent having inventories higher than necessary at all times (see Chapter XIX).

Economic Purchasing Quantity. The economic quantity to purchase, Q in Figure 2, can be determined theoretically as an aid to the judgment of the buyer. The problem of economic purchasing and manufacturing lots or quantities are quite similar (see Chapter XX). These problems can be approached by the tabular, the formula, or the chart method. The tabular method is time-consuming because the answer is not known until a number of possibilities are explored. The formula method is developed from the maximum and minimum

concept of the calculus which provides an answer in one calculation. However, any answers should be carefully scrutinized to be sure that all pertinent factors have been considered. A common example, shown in this chapter, will illustrate this point.

None of these methods can be used blindly for several reasons. If the economic quantity will spoil, become obsolete, or require additional space built to store it, then these or other factors may be more important. Whether the tabular, formula, or chart method is used, certain facts must be known about the material to be purchased.

1. Estimated amount used per year.
 - 1.1 Estimated maximum used per day.
 - 1.2 Estimated minimum used per day.
2. Inventory carrying charge, based on the average rate other capital has earned in the business as a whole, plus any interest, taxes, insurance, and unusual depreciation or obsolescence losses. (See page 440.)
 - 2.1 Does this carrying charge vary with the product?
3. Estimated procurement cost for each purchase order.
 - 3.1 This includes such items as the expense of originating the purchase requisitions, and the time spent by major executives in consummating the purchase and by buyers and clerks in investigating markets, securing bids, and placing purchase orders. In addition, the time and money spent in following up the order, the expense of receiving and inspecting the goods, and the final expense in closing up the vendor's invoice accounts should be included in the procurement cost because all these costs are incurred when a purchase order has been released. The determination of this cost involves a fact-finding analysis which finds all the costs involved and divides the amount by the purchase orders written during the period. When the average procurement cost is thus determined, it will be more or less constant until conditions change materially.

One division of the General Aniline and Film Corporation arrived at an average purchase order cost of \$4.34. During the period studied, 850 orders were placed. The orders ranged from \$60,000.00 to several dollars. These costs included only the purchasing department expenses. The additional cost of receiving and inspecting the purchased goods and paying for their invoices involved an additional \$10.32 per purchase order. Thus each purchase order involved a procurement cost of \$14.66.

4. Estimated storage per unit per year.
 - 4.1 Storage charges often are important enough to be included in the calculation of the economic purchase quantity. If space is at a premium and if released space can be and is used for other purposes, then space requirement differentials become economically valuable and should be considered. However, if released space is not used for

other purposes or if the total released space is not sufficient to, say, close off a room or floor and thus save on heat, light, and other services, then nothing is saved by such release. Some formulas base the storage charge on the average number of pieces in storage. If a bin or floor space has been assigned for the storage of a unit, often it is not feasible to constrict the storage space as the inventory decreases. Thus the charge for storage space should include the space needed for the maximum inventory. If the space released, as the stock inventory is reduced, can be profitably used for other purposes, then the average stock inventory can be used for calculating the storeroom charge.

5. Estimated unit price.

5.1 This price often varies with the quantity purchased.

Tabular Approach for Economic Purchasing Quantity. The tabular approach requires additional calculations such as procurement expense per unit, average inventory carried when different quantities are purchased, the value of the average inventory, and the purchase cost of a year's supply at the different unit prices.

Table 1 illustrates one method² of tabular approach for the solution of an economic purchasing quantity. It is self-explanatory and the totals at the bottom indicate that purchasing orders for 500 units at a time would provide the lowest over-all cost for the year's requirements under the stated conditions.

Use of a Formula for Economic Purchasing Quantity. The common variables used in many economic procurement studies involve the average investment in the controlled inventory, the various charges against inventories which are usually measured in percentage, and the charge for storage space which is often determined by the maximum inventory carried (see page 439). The items can easily be set up in an equation which states the relationships. The following simplified derivation is used as an example of how this may be done.

Q = economic purchase quantity.

C = purchase price per unit (includes vendor's price plus freight to plant).

A = procurement cost per purchase order (includes all purchasing, receiving, inspection, and invoice payment expenses divided by the number of purchase orders written for the period, say, of 6 months). See page 109.

I = sum of annual rates (in decimal form) for simple interest, insurance, taxes on inventory (if any), plus average return earned by other capital in the business. See page 440.

² See Chapter XX, p. 446, for another approach to the tabular method.

TABLE 1

Part No. 6610	Part Name Bearing, Main Propeller Shaft				
#1. Annual Requirements #2. Procurement Cost per Order #3. Storage Cost/Unit/Year #4. Inventory Charge as decimals	10,000 \$8.50 .25 .15	#5. Reserve Stock Maximum Daily Use Lead Time in Days Use During Lead Time	200 32 25 800 1,000	Maximum Use per 30 Days Minimum Use per 30 Days	960 600
	50	200	500	2,000	10,000
	225	300	450	1,200	5,200
	\$ 5.25 \$ 1,181.25 \$ 17	\$ 5.10 \$ 1,530.00 \$.0425	\$ 4.75 \$ 2,137.50 \$.017	\$ 4.75 \$ 5,700.00 \$.0085	\$ 4.70 \$12,690.00 \$.00085
#6. Order Quantity	50	100	500	2,000	10,000
#7. Average Inventory = #1 + #6 2	225	250	450	1,200	5,200
#8. Cost Price	\$ 5.25 \$ 1,181.25 \$ 17	\$ 5.10 \$ 1,530.00 \$.0425	\$ 4.75 \$ 2,137.50 \$.017	\$ 4.75 \$ 5,700.00 \$.0085	\$ 4.70 \$12,690.00 \$.00085
#9. Value of Average Inventory = #7 X #8	\$ 1,181.25 \$ 1,181.25 \$ 17	\$ 1,275.00 \$ 1,275.00 \$.085	\$ 2,137.50 \$ 2,137.50 \$.017	\$ 5,700.00 \$ 5,700.00 \$.0085	\$12,690.00 \$12,690.00 \$.00085
#10. Procurement Cost per Unit = #2 #6	\$ 17 \$ 17 \$ 17	\$.085 \$.085 \$.085	\$.017 \$.017 \$.017	\$.0085 \$.0085 \$.0085	\$.00085 \$.00085 \$.00085
#11. Inventory Charge per Year on Value of Average Inventory = #9 X #4	\$ 177.19 \$ 177.19 \$ 177.19	\$ 191.25 \$ 191.25 \$ 191.25	\$ 320.63 \$ 320.63 \$ 320.63	\$ 498.75 \$ 498.75 \$ 498.75	\$ 1,903.50 \$ 1,903.50 \$ 1,903.50
#12. Procurement Costs per Annual Requirements = #1 X #10	\$ 1,700.00 \$ 1,700.00 \$ 1,700.00	\$ 850.00 \$ 850.00 \$ 850.00	\$ 425.00 \$ 425.00 \$ 425.00	\$ 85.00 \$ 85.00 \$ 85.00	\$ 17.00 \$ 17.00 \$ 17.00
#13. Total Purchase Price for Annual Requirements = #1 X #8	\$52,500.00 \$52,500.00 \$52,500.00	\$51,000.00 \$51,000.00 \$51,000.00	\$47,500.00 \$47,500.00 \$47,500.00	\$47,500.00 \$47,500.00 \$47,500.00	\$47,000.00 \$47,000.00 \$47,000.00
#14. Annual Storage Cost for Maximum Inventory #13X(#4 + #6)	\$ 65.00 \$ 65.00 \$ 65.00	\$ 78.00 \$ 78.00 \$ 78.00	\$ 104.00 \$ 104.00 \$ 104.00	\$ 312.00 \$ 312.00 \$ 312.00	\$ 1,352.00 \$ 1,352.00 \$ 1,352.00
Total	\$54,442.19 \$54,442.19 \$54,442.19	\$52,119.25 \$52,119.25 \$52,119.25	\$48,172.63 \$48,172.63 \$48,172.63	\$48,969.50 \$48,969.50 \$48,969.50	\$53,326.50 \$53,326.50 \$53,326.50

R = reserve stock, which is the number of pieces or quantity in stock when the new purchased quantity enters the plant's inventory. It is purely a safety factor and is often set in terms of one or several normal weeks' supply (see page 108), or as a percentage of the order point quantity.

S = storage charge per unit per year, usually based on the maximum quantity stored. See pages 109 and 439.

U = number of units used per year.

Y = total cost of one year's supply.

Then

$$\text{Average stock on hand} = R + \frac{Q}{2}$$

$$\text{Maximum stock to be stored} = R + Q \quad (\text{see page 110})$$

$$\text{Total delivered cost per unit} = C + \frac{A}{Q}$$

Thus

$$\text{Average investment in inventory} = \left(C + \frac{A}{Q}\right)\left(R + \frac{Q}{2}\right)$$

$$\text{Inventory charges per year included in } I = I\left(C + \frac{A}{Q}\right)\left(R + \frac{Q}{2}\right)$$

$$\text{Storage charge per year} = S(R + Q)$$

The total cost of a year's supply

$$Y = U\left(C + \frac{A}{Q}\right) + I\left[\left(C + \frac{A}{Q}\right)\left(R + \frac{Q}{2}\right)\right] + S(R + Q) \quad (1)$$

or

$$Y = UC + \frac{UA}{Q} + ICR + \frac{ICQ}{2} + \frac{IAR}{Q} + \frac{IA}{2} + SR + SQ \quad (2)$$

$$\frac{dy}{dq} = -\frac{UA}{Q^2} + \frac{IC}{2} - \frac{IAR}{Q^2} + S$$

Y is a minimum when $dy/dq = 0$

or

$$\frac{UA + IAR}{Q^2} = \frac{IC + 2S}{2}$$

$$Q^2 = \frac{2UA + 2IAR}{IC + 2S}$$

$$Q = \sqrt{\frac{2UA + 2IAR}{IC + 2S}} \quad (3)$$

Limitations of the Economic Purchase Quantity. Neither of these two methods of determining economic purchase quantities should be taken too literally; they are intended as a supplement to executive judgment rather than as a substitute for it. The final decision of the quantity to buy may be affected by considerations of quality, delivery

date, market trends, possible obsolescence, or depreciation on the calculated quantity, as well as the current price and quantity.

Also, both methods depend on the present value of the inventory. This of course cannot be avoided because any comparative economy studies of possible courses of action where money values are involved are subject to the same criticism. This type of objection is not fundamental but does emphasize the need for close scrutiny and caution in using the results of these equations. Engineering and economic computations are usually dangerous in the hands of the novice, but competent men can use them without difficulty.

Application of Equation. The following example will illustrate the application of the equation:

Example: The production requirement for a casting to be used on a household device is 1,500 units per month. The normal scrap on this part has been 5 per cent per month, owing to rigid specifications and close tolerances. The castings are shipped several hundred miles by rail. The price on these castings has been \$0.77 each, delivered to the shop, but this price does not include replacement of defective castings. The market for the machine is a stable one. The procurement time is about one week if the order does not exceed 750 units. The procurement expense for this item is estimated to be \$6.50 per order. The castings are piled in bins 8 feet square and each bin can hold about 448 pieces. Because railroad and vendor service is good, the reserve stock has been set at 50 per cent of the order point quantity, which in this case means half a week's supply. Net storage space costs \$1.50 per square foot per year. The rate for simple interest, taxes, and insurance plus desired return on capital totals 15 per cent per year.

Equation 3 from page 112 may be used to solve this example.

$$Q = \sqrt{\frac{2UA + 2IAR}{IC + 2S}}$$

where $U = 18,000 + 5$ per cent for normal scrap = 18,900.

$C = \$6.50$ per purchase order.

$I = 0.15$.

$R = \frac{1575}{30} \times 7 \times 0.50 = 184$ (calendar days are used for this calculation).

$P = \$0.77$ per casting.

$S = \frac{8 \times 8 \times 1.50}{448} = \0.214 per unit per year.

Thus

$$Q = \sqrt{\frac{2 \times 18,900 \times 6.50 + 2 \times 0.15 \times 6.50 \times 184}{0.15 \times 0.77 + 2 \times 0.428}}$$

$$= \sqrt{\frac{249,090}{0.9715}} = \sqrt{256,400}$$

or

$$Q = 506 \text{ units or, say, } 500 \text{ units.}$$

If calendar days in the year are used for calculating economic quantities to purchase, the question of holidays, half-days, and days worked per week lose their significance.

Since railroad cars move every day in the year and vendor's working schedules may vary, it is more logical and easier to use calendar days as a basis for economic quantities to purchase. If we assume thirty days per month, then $1,575/30 =$ an average of about 53 pieces used per calendar day in this example. If we divide $500/53$ we get about 9.5 calendar days of stock in each purchase order for this part.

From these figures it is easy to see that, if the procurement cost were reduced to a minimum of, say, \$3.50, owing to a standing order with the foundry, the economic purchasing quantity would be about 370 pieces, or about enough stock for 7 calendar days. The foundry may have to raise the cost per piece if the order quantity is placed too low, because the freight rate per piece may be too high for orders below a certain point.

This formula for economic purchase quantities provides the same answer for this example as the more complicated formula used in the first edition.

If the formula method is used to determine the economic purchase quantity as set up in Table 1, page 111, and, if the middle range of unit price (\$4.75) is used,

$$Q = \sqrt{\frac{2 \times 10,000 \times 8.50 + 2 \times 0.15 \times 8.50 \times 200}{0.15 \times 4.75 + 2 \times 0.26}} = 373$$

but this quantity is too small to utilize the breaking point at 500 units for the \$4.75 price. It is interesting to note that a tabular check based on the \$4.75 breaking at 373 units gives a total cost of \$48,127.11, which agrees with the formula.

If a price of \$5.10 is used in the formula the result is 365 units, which is too many units (above the breaking point) for that price. On the other hand, if the lowest price of \$4.70 is used, the answer is again about 373. This quantity is far below the 5,000 needed to ob-

tain the \$4.70 price. Consequently, the formula and tabular methods applied to this example arrive at the same quantity to give the lowest unit cost for a year's supply.

PURCHASED MATERIALS INSPECTION

All materials should be inspected before the material is paid for to see that the specifications and required performances are met and that the quality received is the same as ordered. Specifications and tolerances on purchase requisitions are not worth very much unless the vendor knows his products are to be inspected. If, for instance, a company has purchased coal on a Btu and ash specification and the coal dealer suspects that no tests are being made, the temptation is always present to furnish anything available rather than the exact article.

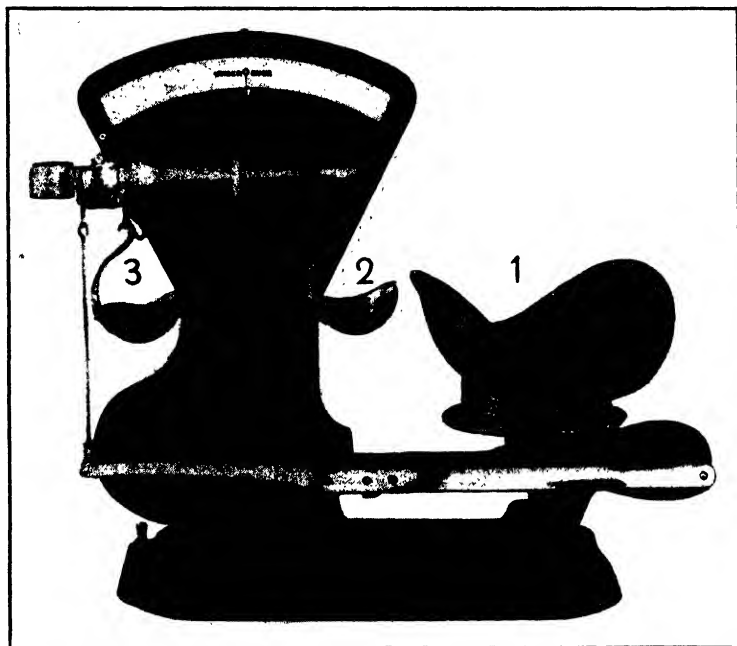
The cost of a detailed inspection of all units of a shipment is usually too expensive, so it is usually done on a percentage or sampling basis. Naturally, certain tests of such materials as coal, oil, steel, and fabrics destroy the material so that a sampling procedure is absolutely necessary. In tests of this kind recognized standard procedures should be adopted to insure a representative sample. Considerable judgment must be exercised in using the percentage method of inspection on a shipment of goods. Such judgment is aided by a thorough familiarity with shop conditions in the buyer's plant and if possible the shop conditions in the seller's plant. Also a knowledge of past performance and the frequency of mistakes in previous shipments have a large bearing on how much of the total shipment is to be inspected. To this end, orders are placed, as far as possible, with approved vendors who have satisfactory records of quality.

Necessity of Checking for Weight or Count. In addition the quantity should be checked. Short counts and incidentally long counts may result from human errors and even the best vendors of quality goods have to be checked on this score. For small or medium weight articles bought by count, the use of the modern computing scale will automatically calculate the number of pieces on the platform of the scales with a high degree of accuracy if the scales are selected properly for the weight range.

Counting Mechanically by Weight. Counting by weight is very simple with a modern counting scale. The procedure explained with the aid of Figure 3 is as follows: First, place all pieces to be counted in large scoop 1. Then the pieces are transferred from scoop 1 to scoop 2 until the indicator of the scale is brought approximately to

zero. Finally sufficient pieces from scoop 1 are placed in scoop 3 to bring the scoop indicator exactly to zero.

Every part in scoop 2 means 100 pieces in scoop 1; every part in scoop 3 means 10 pieces in scoop 1; any pieces remaining in the operator's hand are counted directly. Thus 5 in scoop 2, 7 in scoop 3, and 6 in the operator's hand would total 576. This includes all parts, in



Toledo Scale Company

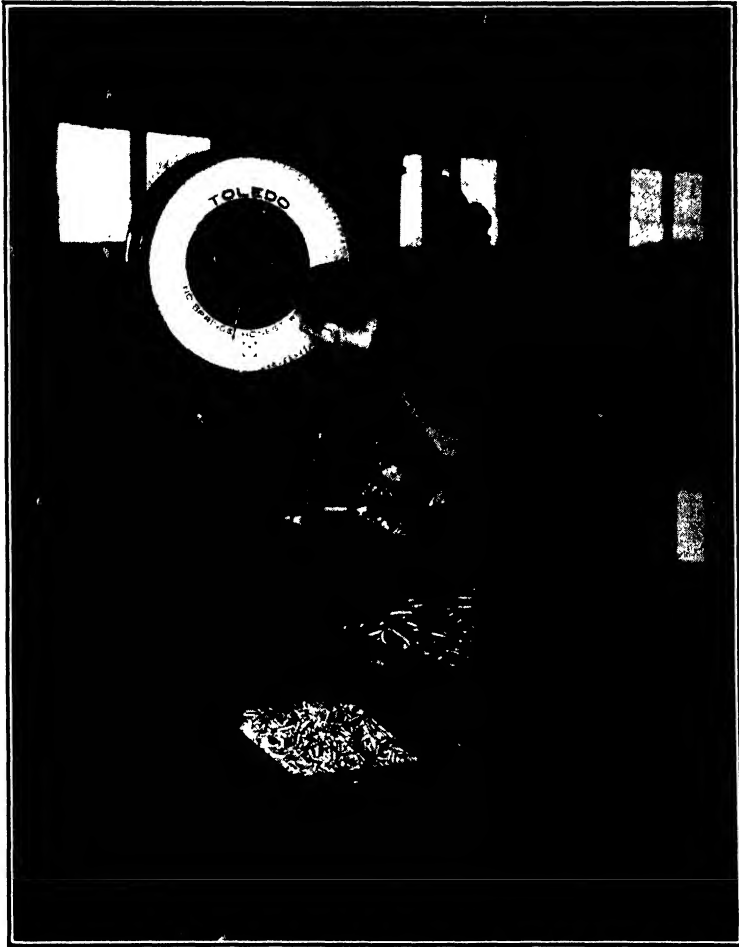
FIGURE 3. Counting scale, capacity 40 pounds.

all scoops and in hand. This simple procedure gives the exact count of an unknown quantity. In practice the count is made in a very short time.

The counting of a predetermined number is just as simple but the process is reversed.

The scale shown in Figure 3 has a counting capacity up to 40 pounds. A small scale has greater sensitivity and should be used for counting small light objects or expensive materials. When scales that were designed for heavy work are used for light weighing, the percentage of error is likely to be too large. Moreover, the large scales are more expensive than the smaller ones so that a more expensive piece of equipment is used to do a poorer job of counting the light objects.

A giant crane can lift a dozen pencils and a 3-ton scale will weigh a 10-pound load, but when equipment is definitely unsuited to the job for which it is used waste of material and loss of time are the natural and costly results.



Toledo Scale Company

FIGURE 4. Heavy-duty counting scale, capacity 1,600 pounds.

Even such parts as forgings and castings can be counted on ratio scales if the ratio is 20 or 25 to 1. This will insure reasonable sensitivity, since the hand count into the ratio scoop will be high enough to get a good average weight of the parts to be counted. The counts thus obtained are more reliable than hand counts and, in addition, are time-saving.

The heavy-duty scale shown in Figure 4 has a counting capacity up to 1,600 pounds. It is best suited for counting heavy objects or cheap light parts in large quantities where slight errors due to lack of fine sensitivity would not be serious.

MATERIALS STORAGE

The physical handling and storage of materials even within any one plant vary widely. Raw material stores are usually located close to a receiving track or unloading platform and as near as possible to the manufacturing departments which perform the first operation on the material. Where inflammables or explosives are stored, insurance regulations may prevent the storing of other goods in the same room or even in the same building. Certain chemicals or their fumes are destructive to other materials. Some foodstuffs such as flour, meat, and shortenings cannot be stored near odoriferous substances like creosote, pitch, or turpentine. For ease of handling, iron ore, coal, and other bulky materials should be piled outside. Paper and other easily damaged goods should not be stored in the same room where brass, steel, or other metal bars are stored. The chance of poking holes into piles or rolls of paper by handling bars in the same room is an unnecessary risk which may increase cost. A good general rule would be to arrange storerooms so that materials that could damage each other would never be adjacent. Good plant layout calls for materials to be located as near as possible to the place where they are used. Therefore, for incompatible materials, a compromise places the ones requiring the most handling nearest to the point of use.

Economic Protection for Materials. Sometimes it is forgotten that material is crystallized capital. The petty cash box in the front office with a few dollars' change in it is guarded with the greatest of care to avoid theft and is accounted for to the penny. Yet hundreds of dollars' worth of small materials, supplies, and equipment are often dependent upon the consciences of a number of people. Careless control of stores produces insidious results. The worker is led to disrespect the value of such prosaic things as castings, screws, paper, and lumber, while the employer in time accepts as a fact that, because his material costs do not vary much from one period to another, no theft is occurring. Actually the amount of theft and other losses from all sources may be the constant. Special industrial detectives have been employed to check on thefts by employees, particularly in those industries manufacturing commodities small enough to be carried out in employees' clothing or lunch boxes.

Moreover, in addition to the temptation for outright theft, there is danger of loose thinking, encouraged by no restraint, which undermines the morale of the working force. A workman spoils a batch of work and surreptitiously disposes of it and helps himself to the necessary raw material to make up for his carelessness. The habits of the working force and their supervisors can easily drift into costly operations and possible subsequent bankruptcy by such loose methods. As an example of close control, a manufacturer of telephone transmitters impressed upon his workers the value of the gold anodes used in plating some of the parts by having the employees who were responsible for them check them in for accurate weighing at the end of every work period. The anodes were checked in and weighed at noon each day and were released when the lunch period was over. The pieces plated during the period were checked with the standard average weight of gold deposited per unit in the time cycle, and in this way any discrepancies could be discovered quickly.

Type of Control Varies with Conditions. The Eastman Kodak Company uses about 5 tons of silver per week for making the silver salts in photographic emulsions. Although silver is rather an expensive material, the company takes no more precaution in storing it than it does for more ordinary things. The silver is purchased in uniform sized pigs which have no thin sections. Each pig of silver weighs about 40 pounds. These chunks are placed directly in nitric acid tanks where they are completely dissolved so that no free silver remains. Since no small pieces of silver are lying about and since it is difficult to get away with one of the large chunks, there has been no loss through theft.

The ever-present law of diminishing returns operates in the stockroom also, and one must periodically analyze the situation to find whether dollars are being spent to conserve pennies. Sometimes conditions around a storeroom become absurd because of red tape piling higher and higher. A major automobile manufacturer at one time assembled his engines on a conveyer line which took about one-third of the space in a long room. The remaining two-thirds of the space was used by the storeroom for that department. The various machined parts came to this storeroom by electric tractor trains from the machine shop, and purchased finished units such as bolts, nuts, and carburetors also were stored in this room. At suitable places along the line, storeroom attendants gave out enough piston rings and rods, engine head and screws for fastening it, carburetor and water pump for one engine as it passed by the various openings. This system worked for several years and kept theft and loss down to a mini-

mun, but, upon further analysis, it was found that the system required too much space for the storeroom in comparison with the assembly space and it required too many men to do the simple job of picking up pieces on one side of a fence and handing them to assemblers on the other side. Moreover, the cost of transporting parts from the machine shop was unnecessary if the engines could be assembled in or adjacent to the machine shop.

Today, this same plant is assembling its engines in a wing adjoining the machine shop. The parts machined in the plant move, for the most part, on overhead conveyers which act as a small bank of supplies, direct to the motor assembly line at the point where the part is used. The purchased finished parts, such as screws, nuts, washers, and carburetors, are placed in the original shipping boxes right at the point of use. The assemblers help themselves so that only one person picks up any one screw or part before it is placed on the engine assembly. Needless to say, the analysis of the old assembly line, along with the storeroom and its system of red tape, pointed the way for savings of over 50 per cent in labor cost per assembled motor. The entire cost of the storeroom operation was eliminated as well as almost the entire cost of the old system of handling materials from machine shop to storeroom to assembly. In addition, a number of economies were introduced into the actual task of assembling the motor.

Such a revised system as outlined above will work with mass-produced articles but may cause confusion in plants operating on job lots. Each plant has its own operating conditions and the storeroom for each division of the plant should be designed and operated for optimum service.

Location of Storerooms. Whenever one sees a line of people waiting for service at a storeroom window, it is a warning signal of potential losses. When the plant has a large floor space owing to multi-story buildings, or when it is spread over a large area, it is usually considered good practice to have several storerooms conveniently located to furnish materials and supplies for departments or shops located near by. Large single-story buildings often have a storeroom placed in the middle of the floor where the light may be too poor for productive processes but where the central location can best serve the various production departments. Floor loads should always be checked with floor-load capacity. Loads increase easily and metal parts often belie their apparent lack of weight to the nontechnical mind of the average storeroom attendant. Buildings have been damaged and even destroyed because it was no one person's duty to watch floor loads and to determine the safe amount which could be stored.

The physical layout of the storerooms and the detailed arrangement of materials are beyond the scope of this book. The questions of what and how much to store are discussed in Chapter XIX.

The purchasing, receiving, inspecting, and storing of materials for manufacturing are important aspects of any system of production control because production control regulates the movement of everything which enters into the product. In addition production control is responsible for having all necessary things available when needed by the manufacturing department, all with a minimum inventory.

PROBLEMS AND QUESTIONS FOR DISCUSSION

Collateral reading is necessary for best results.

1. How important would the purchasing function be for a large pottery producing crocks and cheap artware?

2. How important would the purchasing function be for a large knitted goods plant?

3. How can a purchase followup department reduce the cost of manufacturing a product?

4. Discuss the limitations of any formula developed to calculate the minimum cost-purchase quantity.

5. What effect does the amount of reserve stock of any material have on the minimum and maximum inventory of that material?

6. Solve the following problem illustrating market purchasing: During the next six months, a certain plant has a new sales budget calling for 10,000 units of product XYZ. This particular product uses three pieces of part number 10714 for each unit. Each piece costs \$0.11 delivered in the stockroom. Interest, insurance, taxes, and desired return for capital investment on storage items is 16 per cent per year. Part number 10714 has been stored in open faced steel bins 4 feet by 2 feet by 2 feet high, gross measurement. The usable ceiling height is 10 feet which is served by a ladder on a track for each aisle of bins. The parts come packed six in a carton and the cartons are 7½ inches by 11 inches by 5½ inches. The expense of procurement is \$6.50 for each purchase order sent through on this type of purchased finished articles. Owing to the vendor's manufacturing schedules, purchase orders must be placed eight weeks in advance to insure delivery on promised dates. Vendor's record of promises is good and only 25 per cent of the order point quantity need be carried as reserve stock. Net storage space costs \$2.50 per square foot per year.

How many pieces should be purchased per order to get the minimum cost per piece? How many bins will be necessary, and how much reserve stock must be carried? Is the method of storage feasible for the new production requirements? If not, what changes should be made? How far should the stock diminish before an order is placed?

7. Assume the manufacturer and vendor on part number 10714 offers a quantity discount according to the following table:

2,000 to 5,000 units	\$0.11 each
Up to 7,500 units	0.105 each
Up to 10,000 units	0.10 each
Over 10,000 units	no further reduction

Calculate the minimum-cost purchase quantities on the above quantity discount basis. Are the minimum-cost purchase quantities large enough to get the reduced prices?

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CHAPTER VIII

STANDARDIZATION TO AID PRODUCTION

The function of standardization has been known for a very long time. When the early people of the Stone Age ceased to be complete individualists, they found pleasure and increased security in companionship with other people. Various sounds came to mean certain things and thus speech and language were developed. Quite early in this development there had to be some standardization within the group to make the language serve the community. The written word, the mumbo-jumbo of the medicine man, religion, and clothing were all developed by standardization procedures. Much of this is known as tradition, but what is tradition but a method of doing something for a long time in a standard way?

Esthetic Standardization. Some people are afraid that the modern emphasis on standardization in many utilitarian fields will spread to the esthetic realms. Actually our civilization is getting farther and farther from standardization in this field as our standard of living rises. In other words, the use of standardized utilitarian articles helps to save our money for more individualism in the artistic phases of living.

Even in products which most people would hesitate to standardize, some standard units are usually used. The most individually designed houses and buildings can be made with standard bricks, tile, window frames, doors, lumber, nails, and paint. A manufacturer of floor lamps makes a limited number of standard bases, tubes, reflectors, sockets, shades, decorations, and accessories. These parts can be assembled into thousands of combinations to allow a person almost as much freedom of expression as he wishes.

The designer, the manufacturer, and the engineer are trying to make as many products available to as many people as possible. The world market is so vast that even with reasonable standards individually set by the numerous manufacturers the variety will be large enough to please all but the most fastidious buyer. For this individualist the custom designer, builder, and artist always remain to serve him.

Moreover, the process of standardization and the large-scale manufacturing which often goes with it have produced articles in some fields which are more beautiful and more artistic than were similar products made by hand. The modern automobile, watch, typewriter, and automatic toaster are considered by most people to be better looking and to serve their purposes better than the best products of this type made by earlier, cruder, hand methods.

Scope of Standardization. The scope of standardization is often worldwide. Weights and measures, color as specified and measured by the Coleman double monochromator spectrophotometer, scientific nomenclature, and time are a few of such standards. The ampere, volt, ohm, specific heat, and atomic weights are standard over the world. Time as measured in hours, minutes, and seconds is standard but the Gregorian time calendar may be in the process of change. A large number of firms in the United States and elsewhere are using a thirteen-period year instead of the twelve months. Each period is four weeks long. It is suggested the extra day left over by such a plan be called an all-year's holiday.

More than 400 companies are now using the 13-month business calendar—and the list is not yet complete. Users say “advantageous to have exact comparisons of sales and expenses,” “eliminates necessity of splitting payrolls,” “affords better comparison of operation at no extra cost,” “distortions are eliminated; it simplifies accounting procedure,” “would never consider going back to the old calendar.”

If half of this is true—personally, we're sure it's all true—it might pay other concerns to consider using the 13-month calendar now, and not wait for an Act of Congress to make its adoption universal.¹

Many of the common standards used every day are set by national bodies. Such organizations as the Founder Engineering Societies, American Standards Association, and Congress, by passing legislation, have set a number of standards which are used nationwide. The national fine and coarse screw standards; the Pure Food and Drug Act which determines standards of purity, quality, and grading for meat, butter, and all prepared canned food and drugs; the underwriters' rules for electrical appliance manufacturers; and sizes for men's shoes are all examples of nation-wide standards set by organizations.

¹ *Factory Management and Maintenance*, Vol. 91, No. 5.

Preceding and during World War II, the Army, Navy, and industry cooperated in setting up standards for nomenclature, unique identification, and quality of a large number of commonly used screws, nuts, rivets, and a long list of other hardware parts used in war products. These standards are known as AN standards and they are available for all manufacturers.

The General Motors Corporation also has compiled a comprehensive system of standardization for all kinds of screws, nuts, washers, hinges, and a host of other hardware items. This information is also available for other manufacturers by writing to General Motors, Detroit, Michigan.

Trade associations and similar bodies have the function of determining the sizes or ratings of their industry's products. If this function were left to customer demand, there would be greater variety spread over the present volume. The resulting increase in cost, due to smaller quantities for each size or rating, would have to be paid by the consumer. Thus standardization of this kind tends to decrease cost.

Before united action of this kind was general, it was possible to get almost any odd-size motor, transformer, or gas engine by playing one manufacturer against another to get the business. The National Electrical Manufacturers' Association has acted to determine the desirable range of ratings, prices, and performance standards for many types of electrical goods. These ratings were decided upon after careful study of customer demand to find certain groupings which could be served by a particular size.

Preferred Numbers. In a study of this kind the extreme size of rating on each end is known or has certain limitations. The manufacturer of frying pans, for instance, would probably want to make the smallest one to fry one egg. The largest one would probably be limited by the size which could be handled by a strong chef. The in-between sizes are the difficult ones to decide upon; if individual consumer demands are depended upon the line may get very complicated and unwieldy.

During the last decade or so there has been an increased interest in the "preferred number" system² of standardization. This plan is based on a system of steps in ratings or sizes determined by a series of geometrically progressing numbers. For instance, the "5" series is based on $\sqrt[5]{10}$ and provides steps of about 58 per cent each. The "40" series is based on $\sqrt[40]{10}$ and provides steps of about 6 per cent

² For details on this procedure, see references at the end of this chapter.

each. By using "5, 10, 20, 40, 80" series it is possible to get ratings from about 3 per cent per step to about 58 per cent per step.

Standardization by Industries. Certain industries have done a considerable amount of standardization in sizes and types of products. The manufacturers of shoes, hats, gloves, and shirts have set up systems of sizes for these articles which are fairly uniform from one manufacturer to another. Shoes, for instance, are normally made in men's sizes from AAA to DD in width and, in length, from size 5 to size 12 by half-sizes. Any special shape or quarter-sizes are considered nonstandard, requiring special lasts.

Interplant and industrial standardization is usually initiated and carried on by some trade association or technical group. The American Standards Association consists of forty technical societies, trade associations, and federal agencies representing approximately six hundred national organizations. The purpose of the Association is to bring all interested parties into the discussion and to determine any proposed standards. When such a committee agrees on a plan it represents national opinion and becomes a national standard for the interested industry.

Many companies have learned that both production and distribution costs can be lowered by reducing the number of items manufactured and concentrating on the most profitable. Moreover, their jobbers and dealers can conserve space and money invested in inventories along with the subsequent economy in paper work, personnel, and wages. Such a reduction in a product line can be responsible for a number of economies as shown in the outline below.³

POSSIBLE ECONOMIES RESULTING FROM SIMPLIFICATION OF PRODUCT LINE

1. Faster turnover.
2. Reduced raw materials and parts inventory.
3. Benefits to distributors.
 - 3.1 Reduction of storage and investments costs.
 - 3.2 Savings in warehouse, stockroom, and counter space.
 - 3.3 Increase in sales by permitting concentration on most salable items.
 - 3.4 Reduced inventory losses.
4. Reduced production costs.
 - 4.1 Setting-up time.
 - 4.2 Tooling.
 - 4.3 Materials handling.
 - 4.4 Supervision.
5. More concentration on sales operation.

³ *Modern Industry*, March 15, 1946.

6. Better use of advertising dollar.
7. Built-up inventories of fewer finished products.
8. Creation of production capacity for diversified products not formerly made.
 - 8.1 Higher cash value to be realized for total production capacity.
 - 8.2 Improved relations with suppliers owing to ability to purchase on a more even basis.

The National Bureau of Standards is available for certain aspects of industry-wide and company standardization work. The Bureau will not compete with private laboratories but, for a fee, it will determine properties of materials when such data are not obtainable elsewhere.

When Herbert Hoover was Secretary of Commerce, the Bureau fostered a strong simplification program based on the standardization of screw threads. The benefits of this important program led to simplification in other utilitarian fields. Paving brick sizes and shapes were reduced by agreement of the manufacturers. Hundreds of other product lines were simplified by standardization studies conducted jointly by the Bureau and representatives of the industries concerned.

Under the present federal laws the Bureau of Standards has certain limitations covering activities it may perform for private business. The limitations are listed below.⁴

WHAT THE BUREAU WILL AND WILL NOT DO FOR INDUSTRY

It Will . . .	but	It Will Not . . .
. . . solve specific problems for an industry at its request, and even go into the physical and chemical properties of the articles . . .		. . . engage in abstract, exploratory scientific research.
. . . develop standards upon application from any trade association or other group concerned with achieving basic uniformity, such as antiknock properties in motor fuels, and lubricating qualities in oils . . .		. . . compete with private laboratories or do research to help a manufacturer make a more salable product.
. . . help a manufacturer (a machine producer, for example, who has trouble with a bearing burning out) by sending published papers on the subject or even give him advice from existing Bureau research . . .		. . . help him to design or redesign his product.

⁴ *Modern Industry*, March 15, 1946.

It Will . . .	but	It Will Not . . .
. . . test competitive products and tell each manufacturer how his product stacks up . . .		. . . tell the manufacturer the specific names of his competitors in the test, nor permit him to use the Bureau's findings for advertising purposes.
. . . prepare simplified-practice specifications, cutting down the numbers of almost identical products on hundreds of products . . .		. . . initiate these studies unless asked to do so, or require manufacturers to conform to the recommendations.
. . . answer letters from citizens for information on scientific and practical subjects, mostly of value to the home owner, on such things as fire protection, protecting clothes from moths, paint, and soap . . .		. . . tell them which brands to buy, though it knows the properties of almost all products through its tests of government purchases.

Standardization within the Plant. After all the worldwide or national industries or trade associations have standardized to their respective limits, there still remains much to be done to complete the job in the individual plant. A primary step in good management has been taken when the product, design, materials, methods, machines, and men have been studied in an effort to standardize them.

The product to be manufactured is, of course, the starting point for all standardization moves in the plant. Before the size of the eventual problem is known it is necessary to determine first what products are to be made and then what limitations are to be placed on them. It is generally not sufficient to say a company makes boats, shoes, bread, or musical instruments. No one company makes a complete line of boats, say, from a rowboat through all the various other classes up to modern liners like the *Queen Mary*. Even with such a product as shoes, where size and type differences do not require such a wide variation in machinery as the boat business, no one manufacturer makes all kinds of shoes. The shoe manufacturers standardize on a limited field like men's work shoes or women's fine shoes, and even within such groups there are further limitations such as leather work shoes rather than wood or rubber types.

The tendency toward specialization or standardization within families of products seems to be increasing. The real benefits accruing from division of labor in the factory and the intensified marketing

possible in a narrower field have made both greater profits for the manufacturer and lower costs for the consumer.

Not only are manufacturing plants standardizing on certain sizes, types, and qualities of their products, but also on such properties as performance, taste, food value, chemical purity, and color.

A large butter producer decided to standardize the color of his butter at the lightest natural color by bleaching it in other seasons. Biological chemists showed him the folly of such standardization because the bleach tended to destroy the vitamin A content. The executives of the company immediately withdrew the move to standardize the color by this method.

The manufacturers of electric motors, automobiles, tools, furniture, tires, electric razors, automatic refrigerators, and many other products are constantly testing competitors' models of these articles to see if their own performance standards compare favorably with competitors' products. Standards of this type aim to classify performance into different categories such as over-all efficiency, wearing ability, cutting ability, ability to run cool under load, and color fastness. These standards are set for each model or type to fit certain conditions and price classifications.

Practically all tire manufacturers usually make four or more families of tires, each designed to have certain wearing-ability standards. The range of performance from the cheapest to the most expensive is carefully standardized so that purchasers of any class of tire can know what to expect.

Manufacturers of paint, dyes, upholstering fabrics, and textiles are concerned in large measure with the ability of their products to resist fading or change of color. Paint is tested for its durability under different weather conditions—sun, cold, and rain—for expansion checks and ability to protect the surface of the wood or metal against deterioration.

The best of the early automobile finishes would be considered low grade under today's standards. The early materials depended upon oxidation for hardening and drying, and the process of oxidation continued at a slower rate until the paint was destroyed. The paints and varnishes used on the early automobiles were built up with a number of coats, and the medium-priced sedan body required twenty-one days in the paint shop. The time cycle today is a matter of hours because the number of coats have been greatly reduced and the drying time is a matter of minutes. Moreover, the life of the finishes on a modern car is much greater than the old-time expensive finishes.

Taste Standards. Products like tea, coffee, liquors, cheese, meat, other foods, and gum adhesives for stamps are carefully blended to impart standards of taste. Not all coffee drinkers like the same flavor and aroma in their coffee. Some even want different tastes for different meals or occasions during the day. This demand is met by skillful blending of the green coffee beans, roasted to a standard color and checked often by expert coffee tasters. Standard methods of brewing the coffee are used to enable the taster to determine when to vary the blend or the roasting to bring the taste up to the standard.

It is important to maintain the tastes of different brands of the various foods and drinks so that the customer can be sure he is buying something he likes. Within certain limits, it is possible to standardize tastes by skillfully compounded standard recipes, but often the various flavoring materials may vary in strength enough to give off flavors which are detected and corrected by the expert taster.

Product Standardization. Lately there has been considerable emphasis on the food value of different food products. This emphasis is due to several factors such as caloric content for various diets and, more recently, the vitamin and mineral content. Each of these has required extensive experimentation to determine quantitatively the standards for effective action. These standards are now incorporated into everyday factory procedures, and the inspection to maintain these standards is almost as difficult and expensive as the original experimentation.

Standards have been set for chemical purity of many products. Medicinal drugs, chemicals for reagent reactions, and commercial chemicals are manufactured to predetermined standards of purity which vary according to the final use. Not only is the final product's purity standardized but also a standard process is often used to produce this purity. Absolute alcohol originally was produced by precision distillation under carefully controlled methods. Today it is produced synthetically by a new method to a higher standard of purity than ever before and, incidentally, at a much lower price.

For years commercial clothing designers, artists, manufacturers of paints, printing inks, dyes, and other color users have been trying to name colors for identification. Although beige or nubian rose may be satisfactory names to describe materials sold over the retail counter, they are wholly unsatisfactory as names to transmit color information from one factory to another or from one country to another.

When dress designers visit Miami or Hollywood to view the latest styles it is important that the design and color be transmitted to the home office as quickly as possible. Word description of color has

often proved to be a poor guide for duplication. Today there are color-measuring devices which make it possible to specify colors that are to be reproduced. These devices give colors a number which can be duplicated elsewhere by blending the color to match this number on a similar machine. The color worker no longer needs to know the name of the color or its shade to copy the exact shade of the original garment, paint, or decoration which may be thousands of miles away.

Thus the product, as a starting point for all industrial activity, should be standardized first before any further steps can be taken towards the manufacturing program. It is difficult and even foolish to develop any tools, methods, layouts, or factories until the final form and scope of the product are known.

Standardization in the Design Room. After the kind of product and the limits within its field which are to be exploited are determined, it is necessary to set up design or specification standards which will make it a competitor within these limits.

In well-organized design departments, the members of the department are required to know the standards manual which shows the drafting room practices and procedure. This results in drawings which have standard methods of dimensioning, standard tolerances to fit the need for accuracy on different classes of fits, standard lettering, nomenclature, and identification systems, standard crosshatching for various materials, and other phases of drafting room practice. Moreover, manuals also are quite common that list standard screws, gears, pulleys, bearings, and levers which may be used on the various machines to be designed in the future. (See reference to the AN and General Motors manuals on standards on page 125.)

Special-purpose machinery generally requires an individual design for each order, but the designer is usually asked to consult blueprints or manuals showing the principal dimensions of similar standard parts in tabular form before he designs a new part.

From the viewpoint of the production control department, the standardization of design of special products or parts which go into these products will lead to larger manufacturing lots which ultimately reduces cost.

It is the usual practice in many mass-production plants to have as many common parts in the various models and types as possible. It is interesting to look for common parts used to make automobiles in different price ranges. The Ford or General Motors families of cars use a number of common parts throughout engine, chassis, and body within each family.

The benefits of such standardization of parts design reach up to the more expensive car and down to the cheaper car at the same time. The expensive car gets the benefit of volume production of these parts and thus its cost can be reduced. The cheaper car benefits because the part has to be good enough to be used on a more expensive group of cars, which in turn tends to raise the quality of the low-priced car. Standards of this kind benefit both manufacturer and consumer.

MASTER PART NUMBER RECORD							
PART NAME						PART NO. REPLACES	
GRO. WT.		MAT'L. NAME					
NET WT.		NET ROUGH					
FINISH		MAT'L. SIZE					
1.		APPROVED VENDORS				DATE ISSUED	
2.		4.				REVISION	
3.		5.				CHANGE NO.	
		6.				DATE	
USED ON	QUAN.	USED ON	QUAN.	USED ON	QUAN.		

Minneapolis-Moline Power Implement Co.

FIGURE 1. Master part number record, useful as an aid toward standardization.

The master part number record (Figure 1) is a definite aid to standardization within a plant or corporation. Two copies of this card are filed, one by part number, and one by part name. If part names are used consistently, the cards will point out, for instance, how many different washers are used. In one corporation where these cards were installed, it was found that two divisions had 158 cards for spark plug wires. A brief study revealed that different part numbers had been issued for duplicate wires and that some wires differed in length by an inconsequential amount. The first study quickly reduced the 158 to 50 part numbers and subsequent studies have reduced it to 32 wires which are now considered necessary.

This company has high-grade engineering departments but had not yet thought much about using standard parts as far as possible.

Since each piece of equipment was largely engineered to have its own drawings, it was easier to use a part number and drawing than it was to find the corresponding part on an old machine. The master parts number record makes it easy to find all the similar parts which have been previously designed.

Standard Materials. The standardization of materials is a natural sequence when design is to be standardized. The inclination of the engineer is to design with no restrictions on kind, size, or grade of material. He likes to consider each machine or device as a unit in itself, with its own problems requiring individual attention. Yet in the interests of both design and manufacturing economy it is necessary to organize and restrain such activities. Some of the farm implement manufacturers have issued drafting room standards in which the alloys, size and shape of bars, sheet, strip, and structural steels are rather severely limited. It is felt that sufficient latitude has been allowed for good ingenious design. Any alleged necessary deviation from these standards must be approved by the head of the engineering department. This rule has reduced the number of sizes, shapes, and alloys to a fraction of the number formerly used. In some cases the price of steel will be less owing to the greater quantities of certain standard sizes which can be purchased.

The selection and purchasing of all types of materials (see Chapters VI and VII) are largely based on standard specifications which must be set when the product is designed or developed. Purchasing costs and inventory charges can be reduced if minute differences in size and grade of materials are avoided. A study of such costs to determine whether it is economical to stock one material or another would include in addition to purchasing and inventory costs the differences, if any, of the processing costs.

The extra costs involved in using a slightly larger brass bar than necessary for automatic screw machine operations may not increase the cost of machining at all but the extra weight of brass is removed as chips at a considerable loss in value per pound. The following data will illustrate an aid in determining material size standardization.

Stock Data for 3/4-Inch Brass Rods Substituted for 2 3/32-Inch Stock

(When extra demands for 500 pounds per month are considered)

Cost per pound at machine	\$0.16
Extra storeroom cost if 3/4-inch rod is adopted for new part	none
Extra costs to process 3/4-inch rod over 2 3/32-inch rod	none
Cost of unnecessary 1/32-inch of brass made into chips worth \$0.07	
per pound = $500 \times (0.16 - 0.07) \times 0.09$ (% increase in weight)	
= \$4.05 per month $\times 12 =$	\$48.60 per year

Stock Data for 2 $\frac{3}{32}$ -Inch Brass Rods

(If rods are purchased and stocked)

Cost per pound at machine	\$0.16
Extra storeroom and purchasing costs incurred per year because a new size of rod is carried	\$50.00
Extra processing costs	none
Cost of extra material	none

A comparison of costs for each bar size based on 500 pounds per month of 2 $\frac{3}{32}$ -inch bars, shows:

Extra cost per year for using 2 $\frac{3}{32}$ -inch bars	\$50.00
Extra cost per year for using $\frac{3}{4}$ -inch bars	48.60
	<hr/>
Saving per year by using $\frac{3}{4}$ -inch bars	\$1.40

This saving, however, is predicated on the assumption that 500 pounds of 2 $\frac{3}{32}$ -inch bar per month are used. If less than 500 pounds per month is used, the savings increase by using the $\frac{3}{4}$ -inch bar. A sample calculation shows a method of finding the break-even point with the given data used above.

Let x = quantity used per month when correct size is available.

- (1) Then $12x [0.09 \text{ (cost of brass minus chip price per pound)} \times 0.09 \text{ (per cent increase in weight)}] = y$,
where y = added cost of material per year when larger than necessary bar is used.

Break-even point is reached when y in (1) is equal to extra storeroom and purchasing cost incurred by using the correct bar size.

- (2) Then $y = \$50.00$ (extra cost of stocking 2 $\frac{3}{32}$ bars)

$$\text{From (1)} \quad y = 0.0972x$$

$$\text{Substituting in (2)} \quad 0.0972x = \$50.00$$

$$x = 514 \text{ pounds of brass rod } 2\frac{3}{32}\text{-inch in diameter}$$

which must be used under the conditions stated above to break even on the various costs involved.

If more than 514 pounds is used per month, the saving will warrant the introduction of the 2 $\frac{3}{32}$ -inch brass bar into the purchasing, storing, and inventory records.

Thus it is not safe to generalize that waste is always bad business. In this case the expenditure necessary to obviate the waste shows that for the productive use of less than 514 pounds per month it is cheaper not to carry the extra smaller size in stock.

Facts to be used in such a study should be as accurate as possible if the results are to be worth anything. Very often there is not only the waste of material but extra costs of processing and handling to be considered. To get accurate results, these costs should be obtained from time studies or past cost figures. The final balance should show whether the present production rates will allow a material standardization and also at what production rate the nonstandard or specially ordered material will show a saving over the regular standard stocked material.

It is not always easy to make an economic study to determine when to depart from standard materials. Where a higher quality than standard stock material is necessary for a new part about to be designed, a study should be made of the desirability or economic feasibility of using the higher-grade material for other parts which have been using the next lower grade. New standards are thus created when costs are not seriously affected.

Sometimes color or pattern of such materials as textiles, plastics, and metal screens are used in several or many unique styles to give variety and sales appeal to a line of merchandise. Such variation if not carefully controlled can build up stocks very quickly which in turn can become obsolete, sometimes in surprisingly short periods.

Standard Tools. The standardization of cutting tool materials for various jobs should be done by men experienced in production work. The cutting and machining problems in the metal, wood, and plastic fields require careful study to specify the right cutting tool material.

Today there are many different tool materials available with widely different characteristics. From ordinary carbon tool steels to the group of cemented carbides, the price range runs from 10 cents or less per pound to about \$25 per pound. Between these extremes there is a family of alloyed carbon tool steels, a group of so-called high-speed steels, and another group of alloys called Stellites. Beyond the various cemented carbides, commercial diamonds still are preferred for cutting hard or abrasive materials or for producing a fine finish on plastics or brass.

Some tool materials are selected for their high-speed cutting ability and some for their resistance to shock during their working cycles. The ability to hold a keen edge is very important in some cases. Others must be resistant to corrosion in addition to holding a keen edge:

The proper tools can best be determined by making a list of all the possible materials for the required job. Then, by tests on the actual machines to be used in the shop, the productive capacities of the

various possible tool materials can be compared. During these tests, it is important to use each of the different materials at the recommended speeds and feeds and also to have them ground and shaped according to the manufacturer's recommendations. If the tool has to be heat treated it is very important that the correct pyrometric temperatures be used at all points in the hardening and tempering operations.

After the production rates for the various tools are known, the costs of the tools, labor, power, and overhead should be calculated per unit of product for each tool material. The standards for future purchases of tool materials, and, incidently, machine tools and sometimes processed materials are thus determined to give the most economic unit cost.

Standard Supplies. Standard specifications for supplies are desirable in many plants. There has been mystery and some plain hokum in the purchasing of supplies. Many companies do not pay much attention to the purchase of certain supplies because the purchases do not represent a large percentage of the total cost of doing business. Vendors of these materials generally know of this lack of standards and often capitalize on it.

In the past there has been both considerable mystery and higher costs than necessary for such supplies as window-cleaning materials, sweeping compounds, heat-treating compounds, quenching oils, cutting oils, soaps, brooms and brushes, cleaning powders, carburizing materials, improvers for cast irons, pencils, paper, and towels. Sometimes the lack of standards for buying supply materials not only makes them cost more per pound or per gallon but also use of certain materials may damage the product and the reputation of the manufacturer. Some of them can damage the property of the company. If cleansing agents which are too alkaline are used on floor materials such as linoleum, the floor deteriorates and must be replaced. Window frames have been destroyed by window cleaners which not only cleaned off the film of grease and metal dust but etched away the metal frames.

Many manufacturers have staff men who are capable of analyzing the claims for various supplies. L. A. Flagler ⁵ reports that the Procter and Gamble Company requires about two hundred and fifteen full-time janitors. Each of these janitors uses tools costing about \$4 per year which represents less than 0.3 per cent of the total clean-up costs.

⁵ "Motion Study Applied to Factory Clean-Up," paper presented at Management Conference, State University of Iowa, March 31, 1939.

On the basis of final costs of clean-up, it is false economy to purchase other than the most efficient tools.

By actual test this company determined that head mops which lie flat against the floor are more efficient than ferrule mops. Specially built water containers on casters were far superior to the ordinary buckets usual for mopping operations. Specially designed nonskid sandals increased safety and thereby increased output over that obtained when the janitors wore ordinary shoes.

By determining standards in this way it is possible to look through the advertising claims of the manufacturer and the salesman's optimistic enthusiasm. Moreover, price differentials or concessions can be tested for what they are worth in the cold light of results. Much of the glamour or halo built around certain products by implication or claims disappears when careful examination and study are made.

Standard Methods. Frederick W. Taylor sharply criticized the lack of good methods in manufacturing processes. Later Frank Gilbreth emphasized the need for better methods and standard procedures for workers doing the same job. When each workman is allowed to choose his own method of doing a job, there may be as many ways of doing it as there are workmen on the job. Though this kind of experimentation is desirable, it should be controlled and pointed toward a logical conclusion.

In modern industry, products, materials, tools, methods and equipment, and, to some extent, men have been standardized as an aid to more efficient production. Methods have become so important that motion and time study departments have been developed to improve them and to collect data useful for standards in planning, costs, and incentive wage plans.

The better motion study departments are getting superior results by encouraging and coordinating suggestions from all sections of the plant personnel, from workmen to supervisors. Continued progress and enthusiasm can be obtained by recognizing the source of all suggestions and giving a suitable reward. In this way the whole plant becomes motion-minded and the workers and their supervisors are more likely to discipline themselves by the necessary methods standards. Changes decreed from the top often cause difficulty and resentment which are largely absent under the plantwide educational scheme.

The motion study division is primarily interested in working out standard work places and production centers. This includes an arrangement of tools, materials, and workmen which will require a minimum of effort to do the job. Auxiliary devices are built to aid production. These may be holding fixtures to relieve the hands for more

productive work, or they may be devices to hold or bring the parts and tools as near to the point of use as possible.

Auxiliary tools such as wrenches and screwdrivers can be combined or positioned for easy grasping so that energy and time of the workman are conserved. Here again, it pays to invoke the aid of the shop personnel because they often can release a fund of information if they are properly approached and rewarded.

When an improved method of doing something has crystallized sufficiently to get the support of interested persons it is well to set it up as a standard way of doing the job. Quite often the standard work place and auxiliary tools in their proper position in relation to the workman are described, photographed either with movie or still camera, and placed in a standard methods book. This then becomes a standard to be used in the shop until further improvements are made.

Standard methods and their recording are important in controversies regarding procedure, incentive wages, and defective work. Moreover, it is important to include in the recording of methods the working conditions under which the standards were set. Working conditions do change from time to time, and they may affect earning rates, quality of product, or workmen's health. It is foolish to record time standards to the fraction of a minute and not have any recorded standard for the method of doing the job.

Time study is primarily used to find out how long it takes to do a job *after* a standard method of doing it has been developed and recorded. Too often a job is timed before its various elements are made standard and a false time standard is thus set up. Since so many production control functions depend on accurate time studies made under standard conditions, it is very important to have a firm foundation upon which to build. Just as accurate surveys of ground measurements and contours are necessary for the static structures of the civil engineer, so are accurate time measurements of the production possibilities of a plant necessary for the industrial engineer.

The most generally accepted method of writing operation or instruction sheets is to decide on a sequence of operations at the time blueprints or specifications are first brought to the industrial engineering department. (See Chapter XI.) By subsequent studies, however, motion and time study often has shown the way for a better sequence of operations and sometimes even has removed the necessity for certain operations. Most plants cannot afford to neglect the opportunity to check their methods by the searching analysis of motion study. It is the best way to set up standard methods which, under present conditions, are the best which can be devised. This division of stand-

ardization is seldom completed because human ingenuity properly guided by a competent motion study department can continue to improve methods.

Standard versus Special-Purpose Machines. Machines in general are made in two broad classifications—general-purpose and special-purpose machines. Ordinarily a special-purpose machine is designed to perform a particular operation better or faster than a general-purpose machine can do it. Often a machine of this type replaces several general-purpose machines, and frequently it is designed to manufacture only one product. Whether or not it is profitable to the firm using it depends on the extent to which it is used, and this in turn depends on the volume of business. Moreover, other factors besides extent of use determine ultimate profit or loss to the company: (1) the amount of direct labor saving, (2) the amount of floor space saved, and (3) savings on various other fixed charges.

Undoubtedly special-purpose machinery has a definite place in industry and if used to the best advantage can reduce considerably the manufacturing costs of each part or article produced. Unless every cost is taken into consideration, however, it may actually increase costs. (See Chapter XV.)

As for the general-purpose machinery, it is plain that no machine can serve all purposes and that the term "general" or "standard" is used only in a relative sense. When a machine can be employed for several different operations, it is a general-purpose or standard machine. An engine lathe is a general-purpose machine in machine shop work, although it could not be used to manufacture sheet-metal waste paper baskets. The range of operations that can be performed on a semiautomatic turret lathe is rather wide, but it can be used only in the metal- or plastic-working industry. Yet the turret lathe is considered a standard machine. On the other hand, a bottle-blowing machine that produces only 8-ounce vanilla bottles, for example, is once and for all a special-purpose machine; even within the industry it cannot be used for more than one kind of product.

Most plants of any size have some special-purpose machinery, but the versatility of the plant can be measured by the amount of standard machinery it contains. When a plant is equipped with special-purpose machinery only, it is virtually handcuffed to one product by that very machinery. If the demand for the product should decrease or disappear, the machinery could not be used to produce any other product. A plant with machinery for making pies cannot easily turn to producing bread or cake.

Those plants manufacturing basic products or standard articles which are fairly stable, however, must use special-purpose machinery whenever they can, or they will find it difficult to compete with large plants in the same industries. With the growth of specialization in recent years, the use of special-purpose machinery has increased. Moreover, its use has become more common as plants have grown larger or volume has increased.

Standardizing the Selection of Machines. Any plant having more than one similar machine has another avenue for standardization which becomes more important as the number of similar machines increases. Regardless of whether the machines are general- or special-purpose, there are advantages in having all gear hobbors, or all turret lathes, or all steam shovels, or all sewing machines, or automobile delivery trucks made by the same manufacturer. By such standardization the user gets the benefit of consistent design and appearance in his plant. Though this is not important in itself it does give a pleasing effect to the visitor in such plants used for bakeries, flour mills, and cigarettes to see uniform design and appearance in a group of machines doing the same job.

Maintenance problems are easier if the repairmen can concentrate on one kind of machine rather than a variety of types within a class. For a line of gear hobbors of the same make the maintenance men can better predict when machines will need certain parts replaced to forestall breakdowns. They will become more expert in servicing similar machines. Fewer spare parts need to be stored for emergency repairs where machine types are standardized to give the same maintenance service. Setup men and operators become better acquainted with the machine's operational characteristics, and they should be able to turn out more work with this greater skill and knowledge. Moreover, men can be shifted from one machine to another without the usual slowing down that occurs when a different machine and its controls must be learned.

The element of accident risk and spoiled work due to shifting men around on strange machines is largely avoided when all machines for similar purposes are made by the same manufacturer.

Manufacturers of machines recognize these advantages and they know that most of their customers also recognize them. Machine manufacturers generally will extend themselves to give the best possible service to new purchasers to secure approval of the use of their machines in the plant. If the machine's ability to produce is consistent with the user's demands, it behooves the machine's manufacturer to continue this service. The intangible value of continued

mutual interest and support between user and vendor of production tools can become greater as confidence increases.

Job Analysis and Evaluation for Standardizing Job Requirements. An increasing number of companies are using job evaluation to describe, standardize, and evaluate the various jobs in the plant. This program involves writing complete and accurate descriptions of each job and later perhaps arranging the various jobs in categories.

These categories may be for several purposes. One is according to various pay groups. Another may be based on personal and physical characteristics required to handle the job in the group. These personal and physical requirements for each job become a standard specification for the type of person required to fill the specific job.

The detailed procedures of job analysis⁶ are beyond the scope of this text but it may be stated that some jobs require dexterity, others judgment; some require concentration, others great strength of arms, back, or legs. There are many other personal characteristics which may be demanded in any combination for different jobs.

A complete job analysis procedure involves several steps. Each job is studied for its requirements, and in so far as it is possible these requirements are grouped into families which are similar enough to be used by the employment division to hire the men. It is necessary to develop selection techniques in the form of tests and interviews which are successful in finding the right people. Finally checks should be made to ascertain whether the men hired by such procedures are performing as desired and predicted. If not, the original specifications or the selection techniques should be changed.

The importance of proper selection for the job is illustrated by two articles which appeared in *Reader's Digest*.⁷ The first article describes the abject misery of a sensitive twenty-three-year-old person with artistic tendencies on an automobile line. A few quoted paragraphs express his feeling:

There is a shrill note. It is impersonal, commanding, and it expresses the entire power which sets the wheels in motion. The conveyor begins to move immediately. Mysteriously the men are in their places and at work. A man near me grasps the two handles of the air wrench he will hold all day long. He leans forward to each nut. One nut—two nuts—one motor. It is not neces-

⁶ See bibliography at the end of this chapter.

⁷ "Time Clock No. 1135284," Gene Richard, *Atlantic Monthly*, as condensed in *Reader's Digest*, May 1937; "Americana: On the Line," Christy Borth, *Reader's Digest*, July 1937.

sary for him to change his position. The conveyor brings the next motor to him. One position, one job all day.

As I am painting the end of the rod I realize that I am not conscious of what I am doing. My accuracy surprises me. I seldom make a mistake, yet I never have my mind on my work. Perhaps this is why I am able to obtain accuracy, because my subconscious is more capable of this monotony than my personality.

I have worked long hours this week. Each day I go to work in the dark and leave in the dark. I have not seen daylight since Sunday, and it is Saturday afternoon. I feel strangely unimportant and insignificant. I realize how unimportant personal worth is here. When I come in the gate in the morning I throw off my personality and assume a personality which expresses the institution of which I am a part. There is no market for one's personal quality.

This interesting comment from a man who was obviously not properly selected shows all the misery, resentment, and chagrin at finding himself on a job which offered no satisfaction in his inner self.

The second article was written by a man who likewise was disappointed in what the "assembly line" could offer as a satisfactory job for him. However, the second man was a newspaper reporter and his training told him that there is more than one side to a story. He realized that most of the reported "evils of the assembly line" had been written by persons who possessed sufficient imagination and sensitivity to enable them to write well, but by the very possession of these qualities they were bound to be unhappy in any repetitive or routine activity.

This reporter collected his information direct from men on the line. His comments are best when quoted verbatim.

In each instance I informed the worker of my purpose, told him to hide his badge if he feared to talk with that identification in view, informed him that I did not want to know his name and made it plain that he might either answer my questions or tell me to go to hell.

"This thing is silly," said Ben, a minor plant official after I had given him the Richard article. "If I could write, I could match this with as vicious a description of a railway mail clerk's life. Before I came here I poked letters into pigeonholes for 12 hours a day in a rolling, rocking car. I can't conceive of any deadlier monotony than that."

George, who is 72, has been "in production" at one plant for 24 years. He said he feels "like a 30-year old" at the day's end and spends his leisure "visiting around" with friends. . . . "I done all kinds of jobs on this here line," he said with a boastful note. "I

never seen one yet that would drive a man nutty unless he was nutty to begin with. Of course I can see how a man would hate monotonous work. I don't like it myself. I did it once. I worked for the express company. It was monotonous as hell and damned heavy work. I'll take this any day."

One employee didn't go to the movies because the stories were not real "but music—now that's real. I could listen to symphony concerts every night and want more." When informed that Richard, the author whose article had spurred the inquiry, was a musician, Al opined, "Maybe he's sour because he's sick."

Many of the interviewed employees who had been on the assembly line for some time did not believe their job was monotonous. Other jobs were much more monotonous to their way of thinking.

Bert has two daughters. One of them works in the payroll department. "She thinks my job must be pretty dull," he said, "but I wouldn't have her kind of a job as a gift. It must be awful monotonous to sit at a desk all day and fiddle with a lot of figures."

Both articles are interesting because they illustrate what happens when there is a lack of job analysis and standardization or when men are hired with the proper specifications to fit the job.

Too much of the writing on the evils of division of labor, job standardization, and monotony has been done by sensitive, high-strung, imaginative individuals who tried the line and obviously did not fit the job or by others who have never worked under such conditions but try to picture their reactions if they were forced to do so.

There are thousands of good citizens, kind, gentle folk, with an ability to work, who are so constituted that standard production jobs offer them an easy way to make a living. The five-day week, the relatively good pay, make other hard, monotonous jobs much less desirable to them. The employment department's job is to find these men and place them in the jobs best suited to them.

Disadvantages of Standardization. Lest the reader is led to believe that standards and their benefits are unmitigated blessings it is also well to emphasize that the law of diminishing returns is always ready to reduce apparent gains if the process is carried too far. Standards tend to fix things, if only for a time, and this may impede progress. When drawings, patterns, machinery, operations, and even sales approach have been standardized, change is expensive and some industries hesitate to change for this reason.

Standardization in the plant has destroyed many of the old trades, has made serious adjustments necessary to others, and at the same

time has created new occupations. The concomitant disruption of men and their work has caused suffering and strife.

Some even have predicted that the United States is risking its manufacturing supremacy by increasing the tendency towards rigidity of our production methods by too much standardization. However, most manufacturers, if their trade associations do not become too enveloping and complacent, are beset by enough competition to keep them moving away from stagnation.

Serious as these disadvantages may be, they are small deterrents in the general tendency to get the increased benefits which come from well-planned and controlled standards throughout the plant.

QUESTIONS AND PROBLEMS

1. If you had the power, how would you standardize the page and cover sizes of books? What effect would your plan have on the book-using public?

2. How would you change your plan if all the people who create, sell, and read books had to be consulted before a plan would be possible?

3. How would you as an individual manufacturer of box lunches for a community of machine shops, steel mills, and university students attempt to standardize your product? (Lehigh, Pennsylvania, is such a community.) Obviously, every box cannot be put up to order or the cost would be too high.

4. Is style in clothing a form of standardization or is it an enemy of standardization?

5. Why are trade associations better able to set up standards than individual manufacturers?

6. Is the preferred number system usable in the garment industry? Why?

7. If you were a manufacturer of hats, how would you limit your field and why?

8. How would you standardize the production of tea so that the standards of taste could be maintained?

9. How would you standardize the design of and operations for a line of electric motors from $\frac{1}{4}$ to 5 horsepower?

10. Assume steel bar stock now available is 1 inch in diameter. A new part could use $\frac{15}{16}$ -inch stock but no extra machining cost would be incurred if the 1-inch bar is used. Procurement cost per order is based on an average of \$20 for the plant. The 1-inch stock is purchased in carload lots at \$3.55 per hundred pounds. Since the immediate need for the $\frac{15}{16}$ -inch bars would only amount to about 300 pounds for the year it could be purchased either in lots of less than 100 pounds for \$5.25, 100 to 399 pounds for \$4.25, or from 400 to 14,999 pounds for \$3.75. Storage cost for the steel standing on end would cost about 50 cents per square foot. Steel shavings are worth \$5

per ton. How many pounds of $1\frac{5}{16}$ -inch bar steel would have to be used per year before the use of 1-inch stock becomes uneconomical?

11. What standards would you set up for the purchase and use of brooms to use on office floors?

12. What parts of the manufacturing program can be standardized by good motion study techniques?

13. How can the use of general-purpose machines affect the type of personnel in the plant?

14. How can a neighborhood bakery compete with a large special mechanized bakery in making pies?

15. What are the advantages of standardizing on one make of machine where a number are used in one plant? Are there any disadvantages?

16. By what process are job specifications standardized? Is this desirable from a public welfare standpoint?

17. Describe the most monotonous job you have ever had.

18. Is division of labor feasible in the home? in the classroom? in a grocery store? Where would division of labor be detrimental?

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CHAPTER IX

PROCESS ANALYSIS AND METHODS OF PRODUCTION

The engineering work involved in preparing a factory for the manufacture of a new or changed product is one of the important functions of industrial engineering and production control. It involves a searching analysis of the drawings or specifications and the various possible methods of production. Jobs destined for long runs should be carefully studied before production starts to insure the best possible combination of methods which the plant can afford to use.

If the shop is allowed to start serious production on a long-run job without such careful planning, many of the operations may prove to be ordinary or even poor methods of doing the work, the tooling may be inadequate, and the equipment capacities may be seriously out of balance. Any manufacturing program for a new product is generally pushed for production to meet sales demands. Since changes in methods often are difficult during rush periods, poor methods of production may be kept long enough to be accepted as the standard. This pattern has been repeated often in industries with inadequate process analysis.

Labor Relations with Process Analysis. In addition to high manufacturing cost owing to poor process analysis, present labor relations make it imperative to do the best possible process analysis the first time. Labor negotiators, in demands for higher wages, like to point out that production is much greater now per man-hour than when the product started. But if the original process analysis had been done carefully, the production would have been high from the very beginning.

Number of Units to Be Manufactured Must Be Known. Before any process analysis can be made, it is necessary to know the approximate number of units to be produced. Since sales demand eventually governs production, it is evident that the sales division should have some method of predicting the demand for all products. (See Chapter XVII.) After the production budget has been set, it is coordinated with inventories to smooth out the peaks and valleys in production as far as possible. The production budget for each product as deter-

mined for the period is then broken down to show how many parts, subassemblies, or intermediates must be produced.

In addition to knowing how many units of a product are to be produced in a budget period, say six months, it is necessary to have a reasonable estimate of the total number of units which may be sold before the product is dropped or the model is changed. The methods and special tools used to produce a particular item are not only dependent on the rate of production during a short period of a week or a month, but they are affected very much by the total number of parts eventually to be produced. Temporary dies, for instance, can produce fairly rapidly for a limited number of pieces. If the number of stampings, however, runs into the hundreds of thousands, then the best dies obtainable are none too good for the job.

Should Parts Be Purchased Finished? After the component parts of the products have been thoroughly broken down from part lists of specifications and listed, the individual parts should be analyzed to determine how they are to be obtained. Certain screws, washers, and other parts may be in stock for use on other products. Quite often most of the nonstandard parts are made in the plant because they usually can be produced cheaper in one's own plant. However, standard units such as hardware for furniture, bolts, carburetors for automobiles, and motors for oil burners often can be purchased finished from outside manufacturers cheaper than one's own plant can produce them. Some chemical compounds may be standard products for several companies. Others using these compounds seldom can produce them so cheaply even if no patent violations are involved. The organic chemical companies purchase dye intermediates from each other. This branch of chemistry is so complicated that the "know-how" for certain products is a carefully guarded secret which tends to make that manufacturer the best equipped.

Several related factors should be considered in determining the proper policy when goods are to be purchased finished. Ordinary stock items usually can be purchased for less than it would cost to make them unless the use of such items is so great that it warrants the purchase of machinery equivalent to the vendor's equipment. The Western Electric Company makes its own copper wire, screws, and nuts, among other things, because it uses enormous quantities of these items and thus can afford to use equipment equal to that used by the best vendors of such materials.

The time allowed for delivery may be an all-important factor with some items. They may be purchased finished or made locally, almost regardless of cost, if the time factor makes delay expensive.

If an automobile plant has equipment to make certain parts, say chassis frames, there is always the opportunity to have them made by the specialists in this field. Here is a complex problem which should be carefully studied to include all the costs involved. The delivered cost of the purchased frame is a definite amount, but the various fixed overhead costs, such as interest, taxes, depreciation on both the equipment and space, which may be reserved for frames, go on whether frames are made or not. Moreover, not all the usual overhead formerly charged to a part which is to be purchased finished can be saved. Only that portion of the overhead which is incurred by having labor present is saved. If the purchased finished unit must have certain quality requirements, it is necessary to have inspection procedures set up. The cost of this inspection is a charge against the purchased finished item. When all these costs are added to the delivered cost of the purchased frame the price differential may disappear. The social aspects of maintaining local production over purchasing finished materials from the outside may be the deciding factor in close economic studies.

During times of intense seasonal activity, it may be better to purchase some of the required parts rather than to expand the local plant. If machine schedules are full and no relief is in sight for several months, the assembly departments can be kept to schedule by subcontracting certain parts to relieve bottleneck operations. Sometimes bottlenecks which develop in a heavy schedule can be relieved by subcontracting enough of them to eliminate the shortage. If such bottlenecks are highly seasonal or occur only when certain special jobs are run, it may be economically sound always to subcontract the job as needed.

For example, a certain woodmill owner had occasional bottlenecks in his equipment for making large molding. He purchased an \$8,000 machine, but over a two-year period this machine was used only fifty hours per average year. It would have been cheaper to pay his closest competitor several times the usual cost to subcontract these bottleneck operations outside. Moreover, he would have known this in advance if he had analyzed the need for the machine before it was purchased. It is seldom possible to justify any capital expenditure for equipment unless the savings on forecasted production will pay for the machine in a reasonable time. (See Chapter XV.)

PRODUCT ANALYSIS

The unit of product, such as a washing machine, a can of peas, a typewriter, a ream of abrasive paper, a suit of clothes, or a pound

of dye, is the usual basis for estimating sales. The production engineer, however, must work with the component parts of each product. He must know, for instance, how many washers of a certain size, how many yards of silk thread, how many gears, or how many pounds of anthraquinone 30% paste are needed to produce each unit of product. In most plants the engineering design or specification department places this information on the drawings or specifications and material lists. (See Chapter V.)

Products which are manufactured in rather large quantities usually have their parts or materials specified either on group lists which are supplementary to the regular drawing or on the individual drawing for each part. A good material list is a real help in knowing when all the parts or materials have been accumulated, and it contributes to a logical and efficient production method. In most plants the design or process development department specifies the material and makes up the lists. As rapidly as material or parts lists are prepared for new jobs, engineering should send them to the production control department. Current copies of material lists should be kept on file for use when manufacturing orders are repeated.

Use of Parts or Material List in Product Analysis. When the product consists of a complicated sequence of subassemblies or intermediates, the production control department can be more sure of having a complete list of everything required if a graphic listing of the parts is made. Figure 7 of Chapter V shows a method of using numbers only to show a complete list of all units including bolts, nuts and washers, and other fastening hardware to make the final unit number 910.

Figure 9 of Chapter V shows a graphic parts list which is more complete. It shows the names as well as the part numbers. It also has a list of parts and materials in addition to the graphic presentation of the assembly sequence for the unit.

Figure 10 of Chapter V shows a graphic material and intermediate list for a complex dye. This chart is based on the number of pounds needed for 100 pounds of the next highest intermediate (shown in pounds on the left) and the number of pounds needed for 100 pounds of the end product (shown in pounds on the right). Each ingredient has the two quantities listed.

Such complete charts aid production control in listing *all* the materials needed for any product. It is well to remember that the lack of a $\frac{1}{2}$ -inch nut will prevent the assembly of an automobile, or lack of common salt will prevent the synthesis of some organic dyes.

The production control department is responsible for having all materials available in the plant for *all* products on the production

schedule. Consequently, the material and part lists must be as complete as possible.

In plants manufacturing large bulky apparatus, which must be shipped knocked down in subassemblies, a drawing, model, or bundle list is often used for each subassembly, which has its own name and number. (See Figures 4 and 5 of Chapter V.) All the planning, estimating, production, final accumulating for assembly, and costing of the separate parts can thus be associated with the assigned number of the subassembly. These lists are prepared by the engineering office and they show by name and number all the drawings needed to produce the product. In addition, the required number of pieces or pounds for each part is shown opposite the part number. (See Chapter V.)

Often it is difficult for the design engineer to know all the methods and operations used in the shop. Consequently, he may occasionally specify materials that do not lend themselves to minimum factory cost. If the design department is open-minded on such things, no particular harm is done because the production department can check the material specifications and ask for a change when it is indicated. Sometimes material specifications are worked out by representatives from the shop, industrial engineering, and design engineering, to avoid the delay of asking for changes.

Material Specifications on Title Block. Where the material is specified on the drawing for each part, there is no need for a separate material list except to show a compilation of the materials required. Figure 1 shows the drawing for part number P-215577 which has the stock specification in the lower left-hand corner. This material specification is always available for the planner when he needs it.

Whether the material is listed on the drawing, the parts list or a master part number record (see Figure 1, Chapter VIII) the material specialist or the individual planner compiles one or more of the following; the size to use, the gross and net weights, the number of pieces per standard stock length, the number of standard stock lengths per thousand pieces, and the number of pounds of raw material per thousand pieces. These data should be compiled with the idea of using material already on hand as much as possible. (See Chapter VIII, pages 133-134.)

The material requirements as shown on any of these sources of information are usually for one set of parts to make one unit of the finished product. The number of finished units desired then becomes the multiplier to determine the quantity of each material and the number of parts to be ordered by production control.

Often the same material or part appears in more than one type or model of the product. This tendency is increasing because of the emphasis on standardization. Normally, the engineering design office should list the different assemblies which use any given part on the drawing for that part or on a master part record card. (See Figure

ISSUE 1 3/10/127	Redesigned Issue - 2 3/19/127 9/125" was 7/128" 12/16" was 3/4" S.C. at Thread and Shoulder were not Spec. 1/125" Wide Recess at Shoulder was not Spec. (1152618 - E) Issue - 3 5/19/127 1/164" x 45° Chamfer was S.C. Note at Q was not Spec. (1152618 - D) Issue - 4 3/1/128	<div style="display: flex; justify-content: space-between;"> <div style="width: 48%;"> <p>Heat Blue # 48 Finish</p> </div> <div style="width: 48%;"> </div> </div>	<div style="text-align: right;"> <i>P-215577</i> </div> <div style="text-align: center;"> <i>Fil. H.M. Screw</i> Scale $\frac{2}{1}$ </div> <div style="display: flex; justify-content: space-between;"> <div> APPROVED <i>[Signature]</i> INCORPORATED </div> <div> DRAWING <i>[Signature]</i> CHECKED <i>[Signature]</i> </div> </div>
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STOCK SPECIFICATION

Steel			
SIZE	KIND	SHAPE	TEMPER
3/8"	Screw M Rod	Round	
Spec. # 57611			

NOTE:

① Parts with either 1/64" x 45° or slight chamfer may be used indiscriminately.

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FIGURE 1. Method of specifying stock.

1, Chapter VIII.) If such information does not originate in the design room, then the production control department must gather it. Figure 7 of Chapter V illustrates a form used to compile the various subassemblies which use each part. The same form is used to compile the sub- or final assemblies using the first, second, third, etc., subassemblies.

Economic Methods of Operation. Each part is studied from a manufacturing standpoint. Tolerances are critically examined to determine if they are reasonable. All nominal dimensions as stated on the drawing must vary to some degree, and it is the function of the draftsman to see that the variations are within allowable limits. The

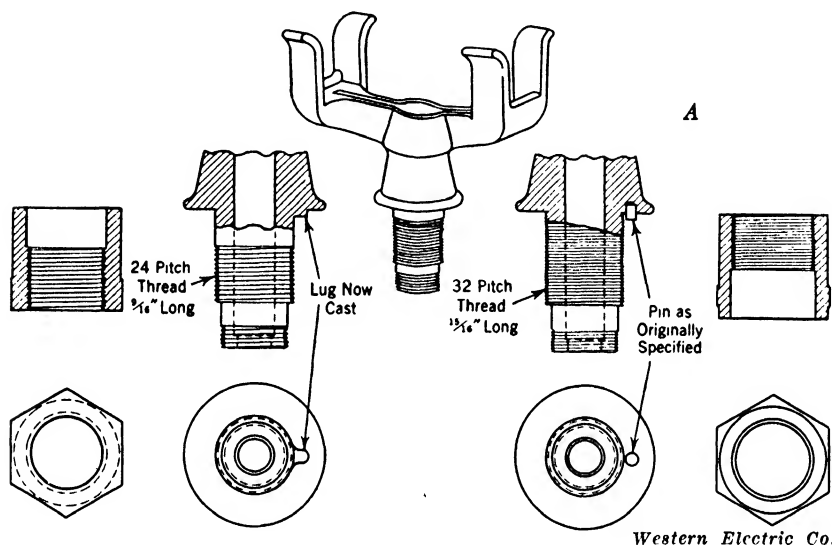
practical limits are those which allow interchangeability without sacrificing the operating quality of the apparatus. The cost of obtaining close tolerances for practically any product increases as the tolerance diminishes. (See page 16.) It is evident, therefore, that any modification of design which permits greater clearances between parts increases the tolerances and thus reduces the cost of manufacture.

Design engineers often are concerned more with the service the apparatus must render than they are about the problems of manufacture. Product analysis requires persons who, by education and experience, are especially fitted to work out changes or modifications in design which will facilitate production and insure lower cost. Sometimes a simple change in design, for instance, which permits the use of more rugged tools, will reduce manufacturing cost because of less tool trouble. Product analysis does not consist of a series of set rules. However, one of the basic rules is to devise methods of manufacturing which will produce the estimated total sales volume at the lowest *over-all* cost. Some concerns have become bankrupt by spending too much money for tooling which could produce far more than could be sold. On the other hand, it is equally foolish to allow the methods to develop carelessly during the preliminary stages of a major production program. Each product should be carefully studied to eliminate the need for corrective factors after the tooling is completed. If and when, however, the sales program is substantially increased, another study should be made to determine whether the present tooling can still produce at the lowest cost.

A questioning attitude is an essential part of any product analysis. The design or formula content of the product should be critically examined and questioned as a matter of procedure before it is accepted in the shop. The materials entering into the product affect the design or formula and often have a great effect on the processing economy. Use of alternate materials may reduce the over-all cost if production has a chance to question the originally specified materials. (See Chapter VI.) The machines and any auxiliary tools should be thoroughly analyzed in the light of the proposed design, specified materials, and the possible changes which may affect the over-all economy of manufacture. Since most manufacturing operations involve manual labor to handle or control the machines, tools, and materials, it is important to consider motion economy before the final recommendations are made. Regardless of the final methods recommended, none should require awkward, time-consuming, or unnecessarily complicated motions to get the work done. Once the product

analysis group realizes the interrelationships between product design, materials, and motion economy in the selection and design of adequate tooling, the over-all cost of the products will be lower.

A good example of this preliminary study to reduce production cost is the cradle support for the original handset telephone. In the design originally submitted by the design engineers, the screw bushing, shown at A, Figure 2, was tapped with a 32-pitch thread at the top.



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FIGURE 2. Example of design change to lower cost and to increase production.

This made it necessary to thread the entire length of the cradle stud. The threading of the $1\frac{5}{16}$ -inch, 32-pitch thread took a long time and the bushing required about twenty-eight turns to assemble it with the cradle. Moreover, this design had a brass pin assembled into a drilled hole to keep the cradle from turning in its socket. Here was one operation of drilling the hole, another to cut off the pin, and a third operation to drive the pin into the hole. Note that the new design substituted a lug cast integrally with the die-cast cradle. Three operations thus were made unnecessary at almost no cost for extra tools or equipment. In the changed design the thread was moved to the bottom of the bushing and was changed to 24-pitch. This change reduced the length of the thread on the cradle stud to only $\frac{1}{16}$ inch and the assembly of the cradle and bushing required only fifteen turns instead of twenty-eight. In addition, the coarse thread was easier to produce on the aluminum-silicon die castings used

for this cradle, and it eliminated almost all thread stripping in assembly.

Effect of Annual Demand on Method of Production. Sometimes the demand for a product will run beyond the original estimates. The public's acceptance for goods cannot always be accurately measured and production rates have to be changed. After the product has been tooled for production at a certain rate the demand may increase considerably. Many products such as the automobile, washing machine,

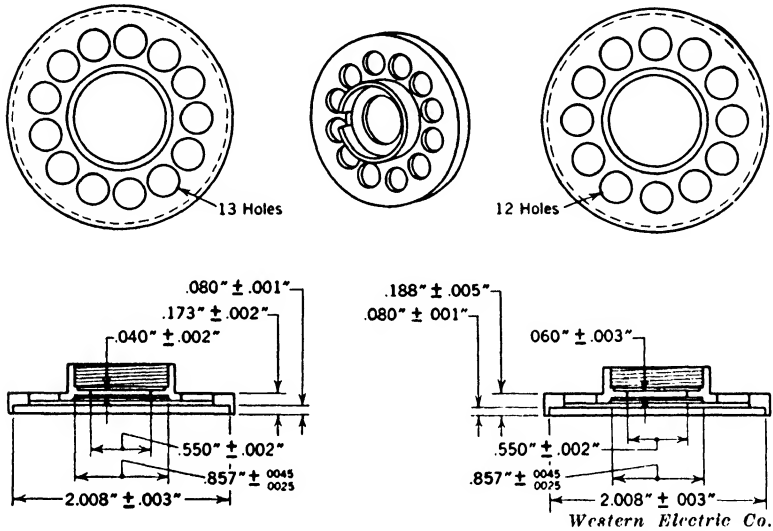


FIGURE 3. Example of design change to increase production.

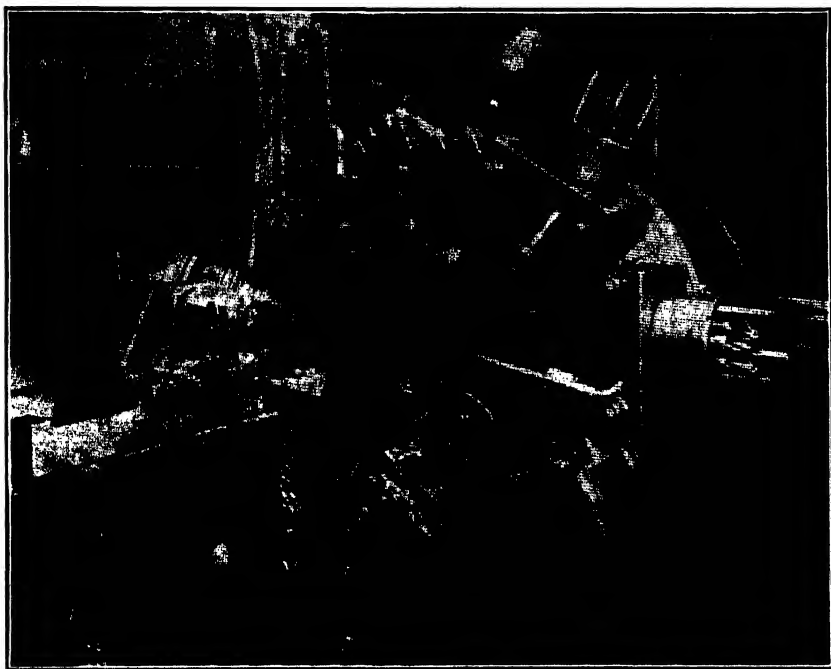
radio, and telephone have grown manyfold from the original production rates.

These periodic increments in demand are helpful to the industrial engineer, because in planning for the manufacture of the next larger quantities he has the advantage of past experiences and can do a better job on the next study. He can make improvements on the old methods which are economically consistent with the larger annual demands.

If annual demand, let us say, should be doubled, it usually is not wise merely to order another set of tools and special equipment to duplicate the old method. Instead, the whole job should be reexamined and studied to determine better and cheaper methods which are economically warranted by the larger requirements.

The Western Electric Company had to increase the production of the transmitter bridge electrode for the original handset telephone from several thousand to about 1,500,000 pieces per year. This part

as illustrated in Figure 3 was made from a brass rod $2\frac{1}{8}$ inches in diameter. Since the part was very thin in some sections, the holes on the outer circle were on close centers and the edges of all holes had to be sharp with no burrs; the part was a most difficult screw machine job. Moreover, the degree of precision required and the chance for distortion increased the difficulty of manufacture.



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FIGURE 4. Machine designed to take advantage of changed design shown in Figure 3.

The first successful method for small lots consisted of machining the part in a turret lathe and subsequently drilling the outer holes in a drill press. This proved to be too slow for the next increase in production and the machine shown in Figure 4 was developed. By asking for a redesign with twelve holes instead of thirteen in the outer circle it was possible to design two special drilling heads, each of which drilled six of the twelve holes. These heads were revolved with the lathe spindle by inserting the three pins mounted on the drill head (see Figure 4) in three holes in the spindle-collet head. The pieces were given the final surfacing after the holes were drilled. Distortion was eliminated and production was increased to sixty per

hour. Later a new method with a better machine was devised when production again had to be increased. The new machine with its improved tools produced about 165 pieces per hour.

Operation Breakdown by Elements for Good Process Analysis. The necessary analytical thinking for good product analysis can also be stimulated by breaking down each operation into the fundamental motions required of the operator. The speed of nonautomatic operations is often set by the ability of the machine operator to load and unload the machine. From a motion-economy point of view, then, any job which can be done with a minimum of physical handling by the operator is the ideal method if it can produce for the lowest *over-all* cost. Such a breakdown of an automatic machine would show no work at all between operations. Figure 5 illustrates this breakdown.

LEFT HAND	RIGHT HAND
No work	No work

FIGURE 5

Of course in most cases a bar of stock would be placed in the machine or parts in a hopper and the product may require occasional inspection to maintain the quality of the product.

The next best solution from a motion-economy point of view is to have the operator place the part in the fixtures during the machining cycle. In this case, the speed of the operation can be no faster than the loading time. The machine automatically ejects the part when it is finished. Figure 6 illustrates this breakdown. If the machining

LEFT HAND	RIGHT HAND
Get part from pan	Get part from pan
Place part in fixture	Place part in fixture

FIGURE 6

cycle were short in this second method, any inspection of the finished parts may involve a few skipped cycles.

If the first two solutions are too productive for the sales demand, a third solution may involve a hand miller with a special air-operated fixture to hold two pieces with air blowout of finished pieces and chips. This work cycle requires more manual work but less expensive machines and fixtures. Figure 7 illustrates the breakdown.

The eccentric pin shown in Figure 8 is an example for such an analysis; other solutions have been developed in Figure 9 for con-

sideration. Material cost in these studies is not a factor in these comparisons since it is the same in all cases.

LEFT HAND	RIGHT HAND	RIGHT FOOT
Get new part	Get new part	Foot pedal to open fixture, release parts, and blow chips
Place new part in fixture	Place new part in fixture	Foot pedal to close fixture
	Operate hand feed in and out	

FIGURE 7

For some operations the simple breakdowns shown in Figures 5 through 7 are not fine enough to get all the facts needed for an intelligent decision. If it becomes necessary to make a close comparison of alternative methods for a high-production job or if equipment must be purchased for a known production capacity, then the time element enters for each fundamental element of the operation. Motion and time study techniques are used here to get the entire time cycle for the operation and the elapsed time for each element of the operation. Figures 10 and 11 illustrate methods of indicating the time for the several elements. Figure 11 breaks the operation down to its fundamental elements which, however, may not always be necessary.

The detailed breakdown of the operation as shown in Figure 11 is an excellent method for developing and maintaining analytical thinking for devising methods of production. If past experience is used too much as a substitute for real analysis of the current production problems, the ability to compete with an alert industry may be seriously handicapped. Motion economy should be used in all operations regardless of the degree of productive capacity which is inherent in the selected method.

Product Analysis for Job Shops. So much can be said about the preparation for manufacturing articles produced in large quantities that one may assume all products should be carefully analyzed in the same way. However, an industrial engineer must be constantly alert to the economic consideration of his problems. In job shops for small units where the number of duplicate parts may be quite low, not much time can be spent studying the manufacturing pos-

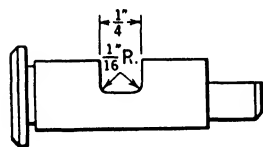


FIGURE 8. Sketch of part for which cost comparisons are made in Figure 9.

ESTIMATED COST OF SLOTTING ECCENTRIC PINS BY DIFFERENT METHODS

Type of equipment	Equipment cost *	Production per hour	Hours labor per 1,000	Labor cost		Production schedule required to justify equipment cost over Method 5
				per 1,000 assuming \$2 per hour for labor and burden †	Labor savings per 1,000 as compared against Method 5	
1. Power broach, continuous-chain type	\$14,000 1 machine + tooling	1,652	0.6 hr/M	\$1.20	\$2.80	$\frac{13,900 \times 1,000}{2.80} = 4,970,000$
2. Automatic mills with double air-operated fixture, 2-machine rate	\$6,000 2 machines + tooling	840	1.19 hr/M	\$2.38	\$1.62	$\frac{5,900 \times 1,000}{1.62} = 3,640,000$
3. Handmill—air-operated double fixture and air-blow-out	Mill available \$400, tooling only 2 fixtures	900	1.11 hr/M	\$2.22	\$1.78	$\frac{300 \times 1,000}{1.78} = 168,500$
4. Handmill—single air-operated fixture and air-blowout	Mill available \$250, tooling only 1 fixture	630	1.59 hr/M	\$3.18	\$0.82	$\frac{150 \times 1,000}{0.82} = 189,000$
5. Handmill—single fixture hand-clamp and air-blow-out	Mill available \$100, tooling only	500	2.00 hr/M	\$4.00		

* The equipment cost is only approximate.

† The labor and burden rate is an assumed rate.

FIGURE 9. Table of comparative costs.

sibilities of each part. The planner is more interested in using existing equipment to the best advantage. He will not try to save small amounts by the use of special tools nor can he afford to search a long time for better methods to reduce cost. The low production of such parts usually does not offer sufficient additional total savings from extensive study to be valuable from an economic standpoint.

LEFT HAND		RIGHT HAND	
Minutes			Minutes
0.016	Get pin from pan	Get pin from pan	0.016
0.020	Place pin in fixture	Place pin in fixture	0.020
0.036	For 2 pins		0.036

FIGURE 10

However, large machine parts, even though only one piece is made, may by their unusual size present problems of machining which require considerable time for planning. Sometimes these large forgings or castings are so complex and so expensive that all possible efforts are made to plan every move for their completion. Often these large

MOTION ANALYSIS BREAKS OPERATIONS DOWN INTO ELEMENTS


Left Hand		Eyes			Right Hand	
Operation Time	Motion Time	Description		Description	Motion Time	Operation Time
						
0.013	0.005 0.003 0.003 0.002	PLACE GAGE IN FIXTURE Move hand to fixture Move down over 1st pin Shift eyes to 2nd pin Move down over pin		GET DRILL PRESS HANDLE Move hand to handle Close fingers Wait	0.005 0.001 0.007	0.013

FIGURE 11. Motion analysis to aid in the selection of a good method.

parts are the key to the production of the entire device. The rotor forging for a large 100,000-kva turbine or the casting for a 20-foot valve must be planned and scheduled with great care for each operation from the design table to the completed unit ready to pass acceptance tests.

Special devices and attachments for some of the machine tools may need to be designed and built. Extra precautions to insure safe trans-

portation may be necessary. When the 200-inch diameter glass casting for the largest reflecting telescope lens was shipped from Corning, New York, to California, the planning involved measuring the clearance of every tunnel and underpass from the factory to the rail destination. An extra locomotive preceded and followed the special shipping car and its locomotive all the way to the coast to prevent



Continental Machines, Inc.

FIGURE 12. Method of producing a limited number of parts.

accident. No expense was spared to do the most complete planning job possible.

Alternate Production Methods. Figure 12 illustrates a method of producing a part which is useful if only a limited number of these pieces were needed. The contour of the piece is laid out in multiple on the bar of steel and the holes are drilled. Then the slot is milled through the length of the bar. A metal-cutting band saw such as shown in Figure 13 is used to cut the finished pieces from the bar. Though this method is far too expensive to use if any great number is needed, its cost should be determined and compared with other low-production methods.

Figures 13, 14, and 15 illustrate a method of producing a lot of 1,000 special grain pans. This method does not require expensive

blanking dies for the rather limited number needed for the job. The Continental Machines, Inc., sawed these blanks on a Do All machine at a fraction of what the blanking dies would have cost.



Continental Machines, Inc.

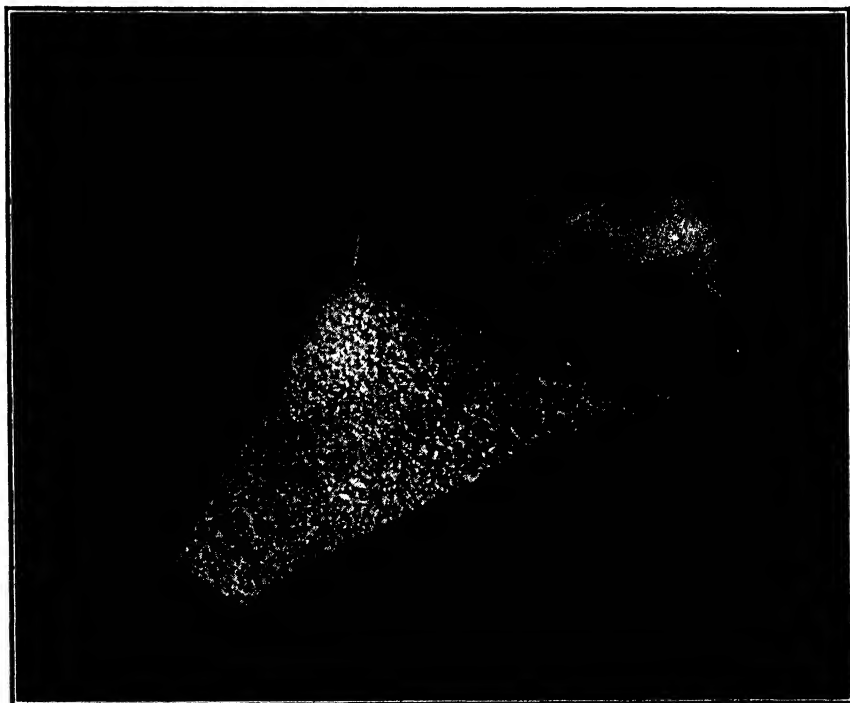
FIGURE 13. First operation for producing 1,000 grain pans shown in Figure 15.

Spinning can often be substituted for press operations where limited production is needed. A study of several jobs that can be successfully produced by various methods of forming metal is interesting to the student of product analysis. Examples given in Figures 16, 17, and 18 show four common methods which could be used to produce the three parts shown. These alternate methods of fabrication include (1) casting and machining, (2) sheet metal construction with welding, (3) spinning, and (4) stamping.



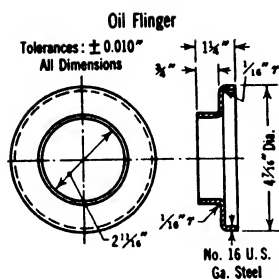
Continental Machines, Inc.

FIGURE 14. Blanks are sawed while held between clamps.



Continental Machines, Inc.

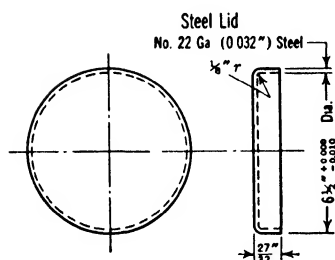
FIGURE 15. Completed pan produced without dies.



	Tool Cost	Cost per Piece including Tools, Labor, and Materials				
		Lot of 100	Lot of 500	Lot of 1,000	Lot of 5,000	Lot of 10,000
Casting and machining	\$ 50.00	\$0.79	\$0.359	\$0.285	\$0.23	\$0.216
Sheet metal construction (welding)		Impractical				
Spinning	26.13	0.53	0.29	0.246	0.215	0.198
Stamping	445.00	4.55	0.94	0.49	0.13	0.08

Milwaukee Spincraft

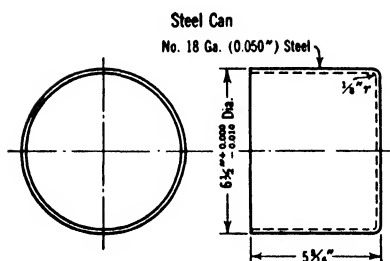
FIGURE 16. Cost of producing an oil flinger by various methods.



	Tool Cost	Cost per Piece including Tools, Labor, and Materials				
		Lot of 100	Lot of 500	Lot of 1,000	Lot of 5,000	Lot of 10,000
Casting and machining	\$ 50.00	\$0.845	\$0.41	\$0.334	\$0.278	\$0.263
Sheet metal construction (welding)	10.00	0.65	0.48	0.39	0.342	0.291
Spinning	6.50	0.215	0.142	0.126	0.10	0.091
Stamping	220.00	2.27	0.477	0.252	0.073	0.048

Milwaukee Spincraft

FIGURE 17. Cost analysis of various methods of producing a steel lid.



	Tool Cost	Cost per Piece including Tools, Labor, and Materials				
		Lot of 100	Lot of 500	Lot of 1,000	Lot of 5,000	Lot of 10,000
Casting and machining	\$ 70.00	\$1.53	\$0.87	\$0.745	\$0.674	\$0.603
Sheet metal construction (welding)	25.00	1.35	0.95	0.775	0.695	0.643
Spinning	12.50	0.925	0.715	0.625	0.593	0.571
Stamping	585.00	6.23	1.31	0.713	0.23	0.161

Milwaukee Spincraft

FIGURE 18. Cost analysis of various methods of producing a steel can.

In considering which of the four methods is most economical, it is also necessary to consider other factors—thickness of metal, weight, and tolerance, which must meet the specifications of the pieces in question. A casting requires a minimum thickness of about $\frac{3}{16}$ inch. Sheet metal construction demands a thickness of at least 0.0359 inch (20 U. S. gage) for economical welding. Both spinning and stamping can meet the specification of 0.0299 inch (22 U. S. gage).

As for tolerance, casting requires $\frac{1}{16}$ inch; sheet metal construction $\frac{1}{32}$ inch; spinning and stamping, 0.010 inch. These factors are important where exacting measurements must be held.

On three jobs—the forming of a steel lid, an oil flinger, and a deep drawn can—the cost analyses are laid out to show production comparison in various lots. The five columns tell an interesting cost-per-piece story. The costs per piece in the tables shown in Figures 16, 17, and 18 include the cost of the tools, labor, and material. Neither casting nor welding methods could compete in these studies. In all cases they were higher in cost, regardless of the lot size. The real comparisons were between spinning and stamping for these parts. Many people regard spinning and stamping as strictly competitive methods of forming. The noncompetitive character of these two methods of forming metal is clearly evident by an examination of the facts. The truth is that in small quantities spinning is the most economical method of fabrication; in large quantities, stamping costs less money. Each does the job best according to the quantity of finished pieces wanted.

A new method of heat-treating certain machine parts has been developed to increase the speed of the operation. A bar of steel which will respond to heat treatment is placed within a wound coil or inductor carrying a high-frequency alternating current. When sufficient power is supplied, the heat developed is sufficient to bring the surface zone of the bar up to the critical temperature of the steel in a few seconds.

Quenching of the heated zone is provided at the exact instant necessary by pressure jets of cooling liquid ejected through orifices that are integral with the inductor block. In this manner quenching is accomplished without permitting air cooling, and handling from heating position to cooling position is eliminated. Form and dimension are controlled by a highly accurate mechanism for varying the magnetic flux, plus a variety of inductor shapes coupled with time control apparatus.

It is characteristic of high-frequency alternating current to concentrate its flow at the surface of a conductor, and the greater the fre-

quency the greater is this tendency. This is known generally as "skin effect" and it has an important influence in heating only those volumes which are near the surface of a mass.

When an inductive high-frequency current flows through a piece of metal the magnetism of the piece is progressively destroyed as the heat of induction is progressively increased.

When the heat becomes great enough it serves to choke off the hysteretic action by destruction of magnetism, and heating due to this

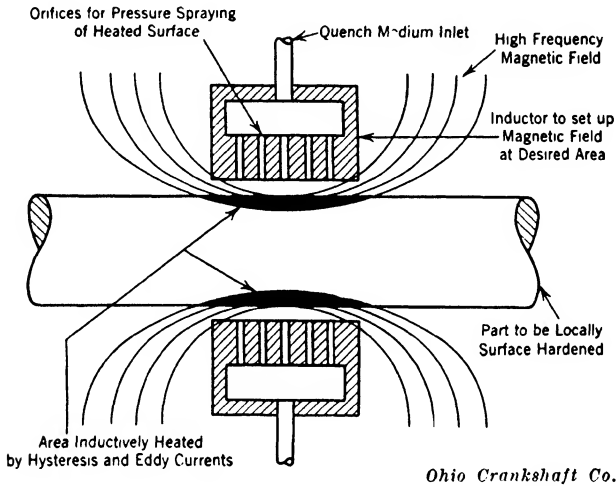


FIGURE 19. High-frequency-current heating process.

cause is maintained in what may be called a state of suspended animation.¹

As each layer or infinitely thin circumferential strip reaches its critical temperature, further heating in that layer is progressively checked by the increased resistance developed to current flow. This increased resistance still further cuts down the eddy currents to a fraction of what they would be if the piece being treated were cold.

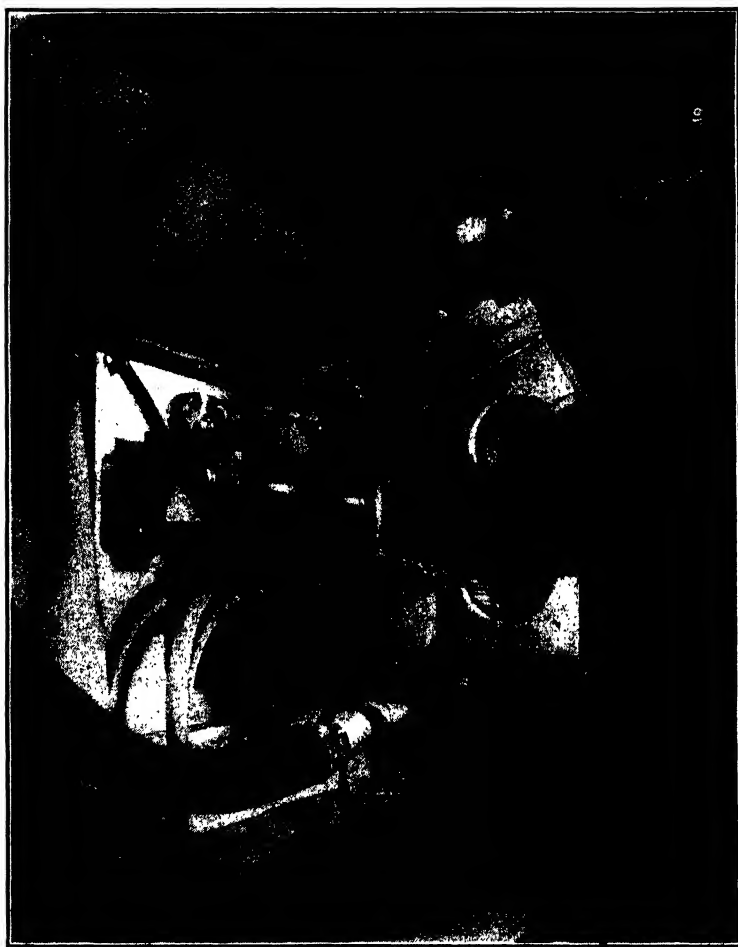
Figure 19 shows diagrammatically how the process works. The part is heated and quenched in one continuous operation.

Figure 20 shows a view of special equipment for hardening crankshaft pins and similar parts.

The usual ten-bearing, motor-truck-engine crankshaft can be hardened at the rate of 30 pieces per hour with two Tocco machines and one operator.

¹ Description from Tocco Literature, Ohio Crankshaft Co.

This method of hardening bearings for heavy-duty crankshafts has resulted in a five- to tenfold increase in the mileage obtained between regrinds, owing to the reduction of wear on the shaft. The original



Ohio Crankshaft Co.

FIGURE 20. Special high-frequency heating device for hardening crankshaft pins.

bearing clearances are maintained longer. As a result, oil pressure is maintained and oil consumption does not increase.

New methods, materials, machines, and processes are constantly being developed. Any plant which fails to keep informed of all new developments in its field may lose its competitive position suddenly if others in the field are alert. The personnel in charge of product

analysis must be constantly in touch with the current magazines and other publications which discuss the plant's products or their methods of production. Moreover, in some shops, the various alternative production methods must be analyzed and selected to provide the lowest over-all cost for the quantity to be currently produced.

The quantity to be made has an important bearing on the ultimate production cost. However, there apparently are economic limitations which tend to control the size of the plant. The highly mechanized plants have large fixed costs and their success depends largely upon having nearly constant output. Often labor cost in this type of plant is a secondary matter since material and overhead constitute such a large proportion of the factory cost. Too frequently, the fact is overlooked that a plant having enough of the latest equipment to produce, say, 100,000 units per year has most of the manufacturing advantages of another plant able to produce, say, 1,000,000 units per year with the same type of equipment as the first plant. Some advantages such as savings from purchasing greater quantities, sales concentration, and less top executives' salaries to distribute per unit of product may accrue to the larger plant. But the fixed cost of the smaller plant, with the same productive efficiency, may be so much less that, during slack times, losses per unit of product may be less.

Probably the most important restriction on the growth of industrial establishments is the limit of ability of the human element which must manage them. Industrial organization and development has made great progress in the last fifty years but it never can become automatic or even routine. The procurement of larger numbers of better trained and more intelligent persons with physical endurance and the will to use it is the greatest problem in any industry large or small. Dexter Kimball, retired dean of Cornell University, further states:

It is no secret that the greatest problem of large industrial corporations today is not that of obtaining technical skill or constructive ability, but rather the securing of vision, foresight, and managerial ability that can direct the complex activities of large enterprises.

QUESTIONS AND PROBLEMS

1. What effect does the product have on product analysis procedures?
2. How much authority should the product analysis group have over the design of a part?
3. What effect does the quantity produced have on product analysis?
4. What new functions does product analysis introduce?

5. What factors are important in checking whether it is wise to purchase or to make the broom handles in a broom factory?

6. Under what conditions would it be desirable for a machine shop to make its own $\frac{1}{4}$ -inch twist drills?

7. Make a product analysis of the stator frame shown in Figure 21, production to be 1,000 pieces per year. The product seems to have a long steady demand.

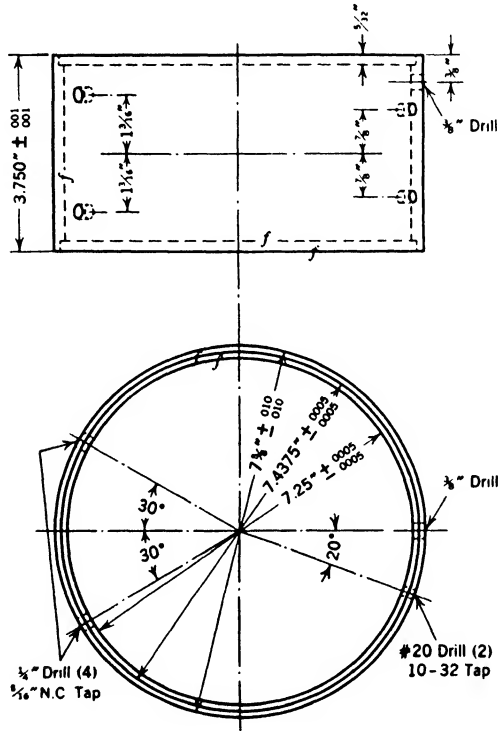


FIGURE 21. $\frac{1}{2}$ -horsepower induction motor stator frame.

8. Specify the material completely for the stator frame shown in Figure 21.

9. What effect does the rate of production and the estimated total production have on process analysis?

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CHAPTER X

SMALL TOOLS AND TOOL CRIBS

A tool is defined as an instrument or device to facilitate mechanical operations. This definition is very broad and includes all machines, equipment, and auxiliary devices used in the production of all kinds of goods. This chapter is concerned with only one classification known as *small* tools. Even with this restriction the term covers an immense field.

Small tools are difficult to define because they have such a wide range of functions. Moreover, production nomenclature is suffering from a lack of terms to differentiate clearly between tools with similar names but with widely different uses. Auxiliary devices or attachments which are specially designed and built to hold work are called fixtures. Tools, however, such as lathe chucks, milling machine vises, and other standard manufactured devices for holding work or other tools would seldom be called fixtures. Special devices or tools used to hold work and also to locate and guide the drilling, reaming, counter-boring, or tapping of holes are called jigs. The word "die" is used for a number of different kinds of tools used in blanking, drawing, threading, drop forging, die casting, Bakelite molding and a host of other operations. In addition, there are large families of tools such as drills, taps, reamers, mandrills, arbors, milling cutters, hammers, saws, knives, tool bits, shears, collets, sleeves, chisels, and measuring tools which help to confuse the definition of the term small tool. The variety of small tools is almost endless. The range is from the tiny drill used in making watch parts to a pair of 6-ton drop forge dies used in forging an engine crankshaft.

In addition to these, small tools also include a still wider variety of auxiliary devices used to aid production. A few examples from several diversified industries will illustrate this. The producer of the hard-type sugar candies such as lemon drops, all-day suckers, and other molded shapes uses a pair of rolls with the proper impressions in the surfaces to make each shape. These rolls must be machined and the die impressions sunk by methods known to toolmakers. The rolls are really small tools which are inserted in the machine and

geared together to squeeze the warm taffy-like candy into the impressions.

The different-shaped removable nozzles used on marshmallow-topping machines for producing fancy cookies are classed as small tools because they are attachments to the machine and aid in producing a variety of different types of cookies.

Olives for the fancy grocery trade are packed in glass with the aid of a small tool which looks like an elongated clothespin about 12 inches long. The tweezer-like tool is used to position the olives carefully in the glass container.

The ordinary pottery factory, which produces the medium or cheap ware sold in the usual retail stores, uses a number of plaster of Paris molds to produce the article from liquid clay. These molds are filled with clay which is about the consistency of thick cream. This mixture is allowed to stand until the plaster mold absorbs enough water from the thin mud to form the thickness of shell desired. The remainder of the liquid is poured out and the fairly well-solidified shell is removed from the mold for further drying before it is fired. These molds are the small tools of the pottery industry and must be designed, made, and stored the same as any other tool used in industry.

While there may be some industries which do not need such auxiliary devices to perform their operations, there are some, notably the metal, wood, plastic, glass, and many others, which use a large number and variety of small tools. The average machine shop has a long list of small tools which are necessary before they can even do ordinary job work. They need various sized drills, taps, reamers, gages, milling cutters, tool bits for lathes and other machine tools, wrenches, dies, arbors, chisels, and so on, depending upon the primary purpose of the shop.

These small tools enable the machines to produce a larger variety of work. Often through holding devices or fixtures attached to machines it becomes possible to hold work more rigidly and at the same time the clamping time can be materially reduced. Special devices¹ called jigs, used for locating and guiding other small tools, increase production, while at the same time these tools enable the workman to produce higher quality goods.

The use of some classes of small tools reduces the degree of skill required to the point where semiskilled workmen are now able to do better work with more consistent quality than skilled labor could do without the special fixture, jig, or die. The skill of the designer and

¹ See Chapter II for a description of how jigs can increase production.

the toolmaker is built into such tools which enable others without this skill to produce complicated articles. Large groups of unskilled people are thus able to participate in industry with only the short training time necessary to learn a specific job. These specific jobs used to be a part of a difficult and skilled trade when the part was made by fine mechanics.

This development in small tools is going on rapidly in all types of industry but not always for the same purpose. In some instances special tools and devices must be built to conform with insurance or governmental regulations. Special devices and protective clothing are demanded for all workers who blend tetraethyl lead gasolines, because of the dangers involved.

No workman today is allowed to oil moving line or countershafts unless he is supplied with special tools which can be operated safely while the machinery is running. The use of better bearings in some plants, oil saturated or antifriction, has often removed the very necessity of oiling except at infrequent intervals. Compensation laws have had a wholesome effect on industry by making operations safe through the use of better and safer tools.

Small tools are sometimes used to get a higher degree of finish or accuracy in the final product. That is, the tool is necessary primarily because the ordinary methods do not have enough inherent accuracy. A good example is the ordinary metal miter box used by the better class of woodworkers. For careful work this box will saw squarely at accurate angles but the actual sawing will take as long as sawing the board without the miter box. There are many examples of jigs or fixtures used primarily for producing accurate or good-looking products where quantity is not important, but such tools should always be made as simply and cheaply as possible to get the desired quality.

Most industries, however, are interested primarily in using new tools to reduce the cost of production. For example, the use of simple punch press dies for steel stampings to replace castings has reduced unit costs in innumerable cases. If demand grows sufficiently to warrant the use of complicated and more expensive progressive dies or even automatic feeding fixtures for the dies, the labor cost per unit goes down to extremely low figures.

This emphasis in modern industry on high production and low costs has brought forward machines and tools which are wonderful to behold. Experience has shown that skill and thought have been transferred to these tools to such a degree that one may be led to believe a machine could be built for practically any purpose. The engineer should be more interested in the problem, "Will it pay?" than, "Can

it be done?" Many mechanical engineers could design a machine to assemble, say a typewriter, but whether it would pay is another matter.

Before large sums of money are spent for tools, it is important to consider the stability of the product. How many parts will probably be produced before the design is changed? Is the product a novelty or does it appear to have a stable future? What are the possibilities of new materials, new machines, new requirements of customers, or new laws changing or making present products obsolete?

If an analysis shows that the product is stable, a study should be made to find possible savings from the use of better tools. The savings are usually judged by the length of time necessary to repay the cost of the tools. There is no point in simply shifting money now spent for labor to care for an increased factory burden caused by an uneconomic, unnecessarily complicated, and expensive tool. The burden costs for tools are a drag on the company's funds for some time, whereas in times of stress labor costs can be shifted according to the need.

On the other hand, the machine should almost always take over the tasks requiring the expenditure of large amounts of energy. Man as a power producer is far too expensive for any industry. The General Electric educational service has pointed out that if a man pumped water by hand continuously for ten hours he would be able to raise about 14,000 gallons 10 feet. Since one kilowatthour is a rather husky unit of 2,655,200 foot-pounds, the man at the pump would produce $(14,000 \times 8.33 \times 10) / 2,655,200$, or about $\frac{1}{2}$ kilowatt-hour, assuming the electrical machinery to be about 90 per cent efficient. This day's work at current rates for power in different districts would be worth from $\frac{1}{2}$ to 3 cents. Similarly, other manual jobs such as shoveling loose dirt and lifting packages into a truck developed $\frac{1}{4}$, and $\frac{1}{5}$ kilowatthours respectively. Obviously, the figures for a day's hard muscular work, expressed in cost for electricity to do the same job, focus attention on the possible need for machines and tools to do this type of work.

It is not always easy to tell whether the expense for a specific tool is justified unless a study is made of each one. The most important element to consider in the adoption of small tools is the economic benefits to be derived. These benefits are forthcoming only when the tools are actually used. The controlling factor on the credit side is the amount of labor, overhead, or material saved by the proposed tool.

The method of calculating the economic value of a new tool is quite similar to the method used to determine when a machine should

be replaced. There are slight differences but not enough to prevent the use of the same forms if it is desired. (See Chapter XV for these forms.) For the purpose of filing the studies made of new tools, it is better to have a separate form for each tool to prevent confusion. After the tool has been placed in service it is always wise to check

TOOL ECONOMY STUDY
(For Data See Reverse Side)

Present tool used on Part Number _____ Operation _____ Date _____

Proposed tool name _____

		Credits	Debits
Saving per year in direct labor and labor burden (Item E)	\$0000.00	.....
Saving per year in power and supplies (Item F)	.....	.....
Saving per year in maintenance and upkeep (Item G)	.....	\$ 00.00	
Saving per year in fixed charges (Item L)	.....	000.00	
Saving per year in unusual charges (Item X)	00.00	.....
	\$0000.00	\$ 000.00	
(Item M) Net savings, based on ____% activity (Item B)	0000.00	.....
(Item K ₂) Investment for proposed tool	.....	0000.00	
(Item K ₁) Net resale value of old tool (this item is often zero)	.....	.....
(Item N) Net cash investment in proposed tool		0000.00	
(Item O) New tool will pay for itself in $\frac{0000.00}{000.00} \left(\frac{\text{Item N}}{\text{Item M}} \right) =$		0.0 years	
(Item P) Rate of net profit on additional investment			
	$\frac{000.00}{0000.00} \left(\frac{\text{Item M}}{\text{Item N}} \right) =$	_____%	
(Item Q) New tool will produce $\frac{60 \text{ (Min./hour)}}{0.00 \text{ (Col. 5)}}$		_____ pieces/hr.	

FIGURE 1

its performance against the estimated benefits. The estimated costs of producing the tool along with the estimated savings can be checked by actual figures. In this way the tool design department can check its performance and the management will know when the tool department is doing a good job.

Figure 1 shows one side of a data and calculation sheet which can be used for this purpose. The same symbols will be used as those in Figures 2 and 3 in Chapter XV on machine replacement studies. Since small tools important enough to have an economic study are usually used on only one job and seldom used on more than several

DATA FOR PROCESS ON BOTH OLD AND PROPOSED TOOLS

1	2	3	4	5	6	7	
Job or part number of all parts to be run with new tool	Operation number	Number of pieces required per year	Minutes per piece with setup time prorated		Time in hours for the number required per year		Remarks
			Old method	New tooling	Old Method Col. 3 × Col. 4	New Method Col. 3 × Col. 5	
					60	60	

(Item A) Hours saved per year (Col. 6 ____ hrs. - Col. 7 ____ hrs.) = ____ hrs.

(Item B) Percentage of year proposed tool will be needed

$$\left(\frac{\text{Col. 7 ____ hrs.}}{\text{Working hrs./year}} \right) = \text{____ \%}$$

(Item C) Saving per hour in direct labor (old method \$____ per hour - proposed tool \$____ per hour) = \$____

(Item D) Labor burden (part of factory burden incurred because labor is present) ____ %

(Item E) Saving per year in direct labor and labor burden (Items AC + ACD) = \$____ Credit
Debit

(Item F) Saving per year in Power and Supplies (old method \$____ - proposed tool \$____) = \$____ Credit
Debit

(Item G) Saving per year in maintenance and repairs (old method \$____ - proposed tool \$____) = \$____ Credit
Debit

(Item J₁) Taxes and insurance (____ %), plus allowance for depreciation (____ %), plus allowance for interest (____ %) = ____ % for fixed charges on old tools if any = ____ %

(Item J₂) Taxes and insurance (____ %), plus allowance for depreciation (____ %), plus allowance for interest (____ %) = ____ % for fixed charges on new tools = ____ %

(Item K₁) Investment in old tools (neglect book value) \$____

(Item K₂) Investment in new tools (include design, construction and installation cost) \$____

(Item L) Difference in fixed costs (J₁ K₁ - J₂ K₂) = \$____ Credit
Debit

(Item X) For occasional debits or credits not ordinarily encountered \$____ Credit
Debit

A positive value for the items as set up above is a credit in favor of the proposed tool.

FIGURE 2. Reverse side of Figure 1.

jobs, it is not necessary to allow many spaces for different jobs on the top of the data sheet.

To understand properly any prepared formula or credit and debit statement as shown in Figures 1 and 2, one must know what is included and what the limitations are. Again there are several existing formulas² for calculating the economic possibilities of tools, and each has its good points. Most of these formulas attempt to charge any remaining book value of a tool to be replaced as a debit against the proposed tool. The same argument discussed in Chapter XV, page 338, is valid here. One of the main purposes of estimating depreciation rates is to have the book value down to the net actual value at the time the asset is to be replaced. In other words, it is estimated how long the asset can serve before it is paid for by the customers of the company. If obsolescence, accident, or poor estimating cause the book value to be higher than the net realizable value when replacement is necessary, the book value is in error by the amount of the difference. Any remaining book value against an obsolete tool which needs to be replaced is the fault of the person who set the old depreciation rate, and the uncollected sum should be taken from a special fund for obsolete equipment or the profit-and-loss account.

Economic studies³ of this type should be made independently of the general accounting records. It is important to have the proper machinery and small tools to compete with any other manufacturer in the same field. If the engineers and production executives allow obsolescence to creep into a plant, the accountant's books may show assets at a book value far above their worth as producing machinery. Dividends may even be paid when funds are needed to build up the machinery and tools.

Usually in an economic study of a proposed small tool, the old one has no book value. Most small tools are highly specialized since they are good only for the particular operation for which they were designed. Consequently, modern concerns depreciate them quickly, usually in one year or less. However, if an unamortized value does remain, it should carry only its net value to the company. That is, if it costs more to remove a tool from its machine than the salvage value (Item K_1), then the net value is negative. Moreover, the profit-and-loss or obsolete fund should pay, in addition, the cost of removal. The proposed investment (Item K_2) would then be the same as the net investment (Item N).

² *Cost and Production Handbook*, L. P. Alford, Ronald Press, 1934, pp. 815-817.

³ Refer to Chapter XV, p. 337, for further discussion on this subject.

The net investment (Item N) is the additional investment required so that the number of years to pay for investment (Item O) and the rate of net profit (Item P) are based on the cash actually expended for the new tools rather than on the total value of the investment.

Some tool economy formulas estimate the worth of additional capacity to produce after the new tool is installed. If some or all the additional capacity to produce can be used immediately, the value of this added production over that stated in column 3 should be calculated and entered as a credit for the proposed tool in Item X. This credit is calculated by [minimum saved per piece (column 4—column 5) \times additional pieces per year from unused capacity]/60 = hours saved per year by not doing this number of additional pieces by the old method. Hours saved \times (Item C + CD) = saving per year in direct labor and labor burden for the additional capacity used if it can be used immediately. Additional capacity, which cannot be used in the immediate future, should not be calculated as an asset in the present calculation. Items J_1 and J_2 are the fixed burden costs such as taxes, insurance, interest, and depreciation which tend to be constant over the year. Items E, F, and G are operating costs which tend to go up and down with production. Any of these variable costs for the proposed tool may be positive or negative in value and should be labeled credits and debits respectively.

Item E is calculated in part from Item A, which in turn is based on the estimated hours per year the proposed tool will be used. Therefore, Item E contains the factor which expresses the percentage of the year the proposed tool will be used.

Items F and G should be calculated on the actual and estimated costs involved during the year for the tools and methods being compared. Item F for power and supplies is often small and can be disregarded. Item G, maintenance and repairs, which frequently includes cost of periodic inspection is usually quite closely connected with production volume.

Some tools, such as punch press dies, drop forge dies, and others, require periodic overhauling or resinking. In addition, where production is large or where possible breakdowns would be serious, it is necessary to have one or more spare tools ready for action. Where drop-forging plants are producing large quantities of forgings more or less continuously, die studies are made to determine the number of forgings per sinking (x), the number of forgings needed per year (y), and the length of time in hours to resink a die (z). Then y/x = number of resinkings per year and $z(y/x)$ = number of hours of labor needed per year to keep enough dies ahead for production of this part.

The cost of such maintenance should be charged in Item X when it occurs. Under this scheme one die is needed as a spare at the hammer, one in the hammer, and enough in the tool shop always to have one coming out when the worn die from the hammer is returned to the shop for resinking. Other classes of tools also may have high maintenance costs which should be carefully estimated in making economy studies.

Interest, tax, and insurance items are usually handled by a fixed policy of the company. Some calculate these only on the depreciated value at the beginning of the year. Others calculate these items on the entire investment over the life of the equipment. The first method is more logical and probably is the only one that can be defended from a pure depreciation angle. However, the second method is more conservative, and, when the ever-present menace of obsolescence is considered, there is less risk in conservatism. This issue may not be so vital with small tools as it is with machine tools because the life of small tools is generally shorter; and thus depreciation and other fixed charges are easier to determine.

The results of any tool economy study can be no better than the data from which they are calculated. The information for each item should be estimated with considerable care to get all the available facts.

Tool Design. In the best plants, the tooling of a job begins with the design of the product; that is, each part or unit is studied to make certain it is adapted to efficient processing. The design department tries to avoid as much criticism as possible from the production department by having men with planning and shop background to look over the preliminary drawings before final design is released.

In some plants, the engineering division designs the product and the tools in an arbitrary fashion, giving the foreman no alternative but compliance with the prescribed plan. Other plants have a scheme of collaboration between the engineers, the plant superintendent, and the foreman; in a few plants—mostly those not so well organized—the shop executives decide on the methods and the kind of tools needed after the blueprints arrive in the shop.

The majority of plants with modern progressive managements have one or more special designers who are finally responsible for tool design. Where the operation is more than a simple routine one, it is better to get as many suggestions as possible from workmen, foremen, and superintendents working in conferences with production engineers.

The maximum rate of estimated production must be set by the general manager, usually in conjunction with the sales department, before any progress can be made in determining the best methods. The number of units to be manufactured is a very pertinent factor in deciding the type of tools to use. For only a few units, it is cheaper to make them without the use of any special devices, but as the number increases it becomes more and more profitable to build the most cleverly designed tools.

No one group in any plant has a monopoly on the technically clever brains. The recent tendency to teach motion study principles to foremen and workmen as well as to production engineers has paid real dividends in practically all plants where it has been tried. Improvements in methods followed by increased production have been made by suggestions coming up from below rather than being imposed from the top. The psychology is different and much less friction is encountered in getting new ideas into the shop.

Successful industry is built upon cooperation or teamwork among its several divisions. At the same time, it is necessary to set up checking procedures where it is possible for one group to catch errors of fact or judgment without prejudice. With this as a guiding principle, engineers interested in production should be separated from the designing engineers. In turn the production engineers should be divorced from the actual production departments. In this way, we can get constructive criticism all the way from design to the ultimate product. Responsible and intelligent autonomy within these divisions, with mutual respect and understanding for each other, will insure a better product at a lower price.

Design Changes. Often the product analysis men, the tool designers, or the men in the shop can suggest a better method if they know that the product design can be changed. These men should be informed that suggestions are welcomed by the design department. If the design department is autocratic and refuses to listen to suggestions, vital changes which could reduce costs are often lost.

Tool Cost Estimating. After cooperative discussion based on all the facts that can be determined by calculation⁴ or estimation, the selected methods are crystallized by writing operation sheets⁵ with a specified list of necessary tools. Operation (sometimes called instruction or routing) sheets are used in all types of plants where the

⁴ Use tool economy study (see pages 174 and 175) and other calculations (page 173).

⁵ See Chapter XI.

parts need a complex pattern of operations to complete the product. These sheets must be written concurrently or before the tools are specified or designed because the method of manufacture depends upon the selection or design of the tools.

The cost of dies, jigs, and fixtures is an important factor in the production of many products. If the quantity is small, improvised setups may be used which require few if any specially designed tools.

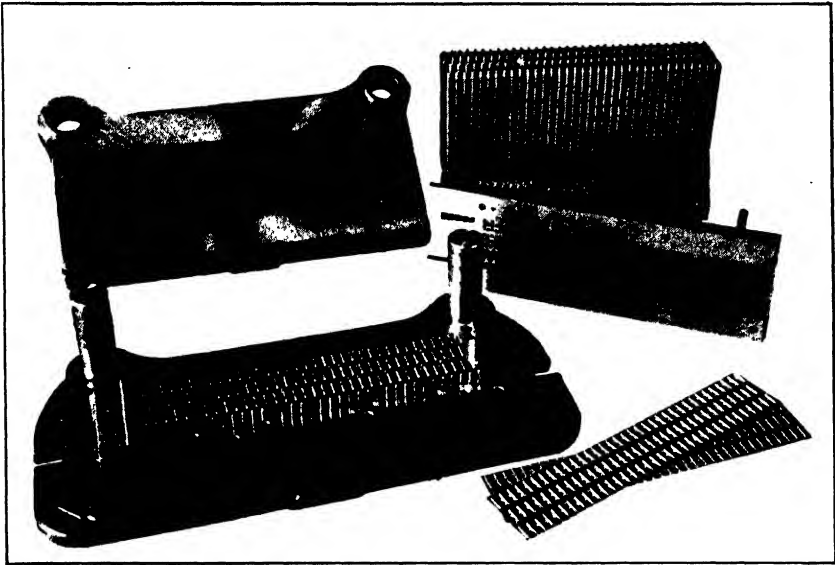
Tool cost estimates are made from previous actual expenditures for similar devices or tools. Records of such costs are invaluable for future estimating and may be used as a later check on the estimated costs. Since it is possible to spend several hundred dollars quite easily on a specially designed die or fixture, it is necessary to have tool estimates as accurate as possible *before* the tools are built; otherwise, it may be found after the expense has been incurred that the supposed profit has been absorbed by excessive cost of tools.

The standard tools which are already available either are in the tool crib of the plant or can be purchased from regular suppliers. However, the special tools such as dies, jigs, and fixtures usually need to be designed to conform to the plant's tool room standards in so far as the special requirements will allow.

Special Tools Are Expensive. Tools necessarily are expensive: first, they are specially designed and built in limited quantities; second, the entire design cost must be absorbed by the one or several tools made; third, they are often made from high-priced materials which may cost from 25 cents up to several dollars per pound; fourth, due to the close tolerances, fine workmanship, and the all-around ability demanded, the average toolmaker is a highly paid skilled workman. Only the finest, most accurate and expensive machinery can be used to produce good tools. In addition, all good tool shops are supplied with expensive, highly accurate, primary measuring tools and gages. To be able to produce tools with tolerances of ± 0.001 inch to ± 0.0001 inch, it is necessary to have measuring tools with a much smaller tolerance. Master gages with tolerances expressed in millionths of an inch are quite common in the tool rooms of many metal-working plants.

The punch press die shown in Figure 3 is an example of a high-grade tool made for exacting conditions. The Gopher Machine and Tool Company of Minneapolis made these tools to produce hot water heaters for trucks and buses. This type of die, made from a number of skillfully fitted pieces, may cost considerably more than \$1,000. Not all dies are so expensive because they do not have to produce under such exacting standards nor are they so difficult to make.

Dies for Short Runs. Temporary dies for punch press work are low in cost because they are quite simple to construct. Figures 4 and 5 illustrate a blanking die^a which required twenty-one hours to produce. The cost of making this Continental temporary die can easily be estimated. It has so few parts and the operations for making these parts are so simple and standardized that accurate estimates can be made. There are only two primary operations in the making of a



Gopher Machine & Tool Co.

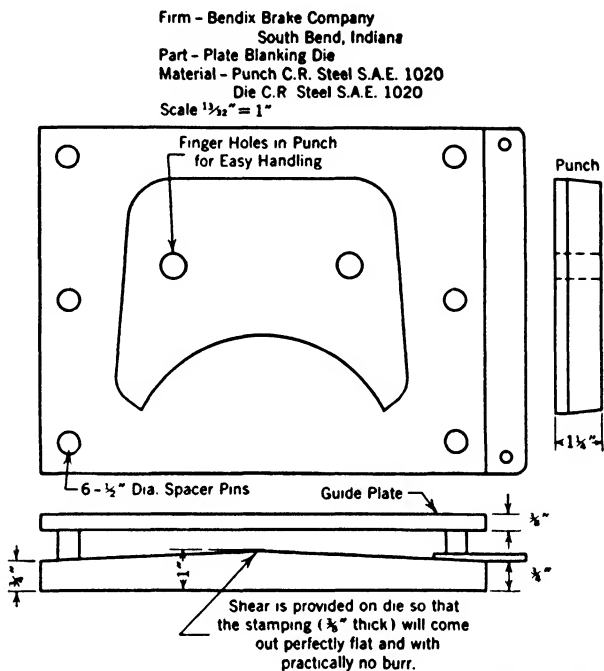
FIGURE 3. Die for bus-type hot-water heater.

blanking die: first, cutting a hole to the size of the blank that is to be produced, through a thin section of steel; second, cutting a very short punch out of steel and fitting $\frac{1}{8}$ inch of that punch to the die hole. The remaining operations such as filing clearance in the die, tapering back the punch, and putting spacer strips between the two plates, are simple details.

The procedure for making a blanking die of conventional design is radically different from the above. Numerous additional steps and operations require skill, patience, and precision. The following are some of the operations which are required in this type of die but which are entirely eliminated in the average Continental type of temporary die.

^a Adapted from a book, *The Continental Process*, published by the Continental Machines, Inc.

1. Purchase a standard die set, or make a "die shoe."
2. Cut a hole through the base of the die shoe on which the die is to be mounted so that the stampings can fall out.
3. Make a "pad" into which the long punch is fitted, or make a flange integral with the punch although this makes it a difficult punch to produce.



Continental Machines, Inc.

FIGURE 4. Drawing for temporary die.

4. Drill, ream, and countersink holes in the die plate and also in the flange or pad of the punch for mounting these two members.

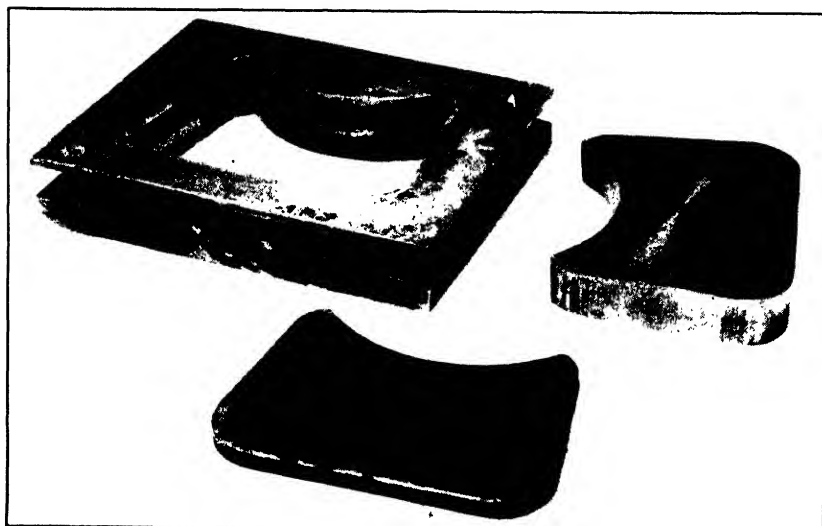
5. Make a stripper plate separate from the die.

6. Grind the surfaces of the die before and after hardening.

7. Securely fasten the die to the base of a die shoe and securely fasten the punch member to the punch holder of the die shoe in such a manner as to make the two members align properly for operation.

It is obvious that there should be a great difference in the total cost of the two types. In many instances conventional blanking dies costing \$100 can be built as temporary dies for \$10, or a ratio of 10 to 1. Rarely would this ratio go below 4 to 1; that is, a die costing \$100 under conventional design would seldom exceed a cost of \$25 even when made of tool steel.

The number of stampings produced per hour is fewer with this method than with the higher cost die because the operator must move the die forward and reset it for each impression. With plain blanking dies or compound and progressive blanking dies of this type, the average output will vary between 70 and 700 per hour. The operation may easily be put on a piece-rate basis. Tests have shown that for



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FIGURE 5. The steel stamping $\frac{3}{8}$ inch thick made in this die requires over 200 tons of pressure to blank it. Therefore, "shear" is provided on the die. (It is 1 inch thick at the center and $\frac{3}{4}$ inch thick at the ends.) This die makes this unusually heavy stamping come out perfectly flat, with practically no "burr." This part is used in the Bendix brake on a motor truck. The holes in the punch are finger holes for easy handling.

plain blanking the hourly output is about one-third of that with a conventional die. In other words, as a basis for comparison, this type of die would produce 333 stampings per hour while a conventional die would produce 1,000 per hour.

Comparing Combined Die and Punch Press Costs. The various ratios and comparisons for the two methods are more readily conveyed graphically. Figure 6 is a graph which shows the difference in application of the two methods. The column at the left represents the cost of the die plus the cost of the punch press work for producing the stampings. The figures across the bottom represent the number of stampings produced. The Continental temporary die cost line (dotted) starts with a die costing \$20. The full lines represent cost of

conventional methods, starting with conventional dies costing two, four, six, and eight times as much as the \$20 Continental-type die.

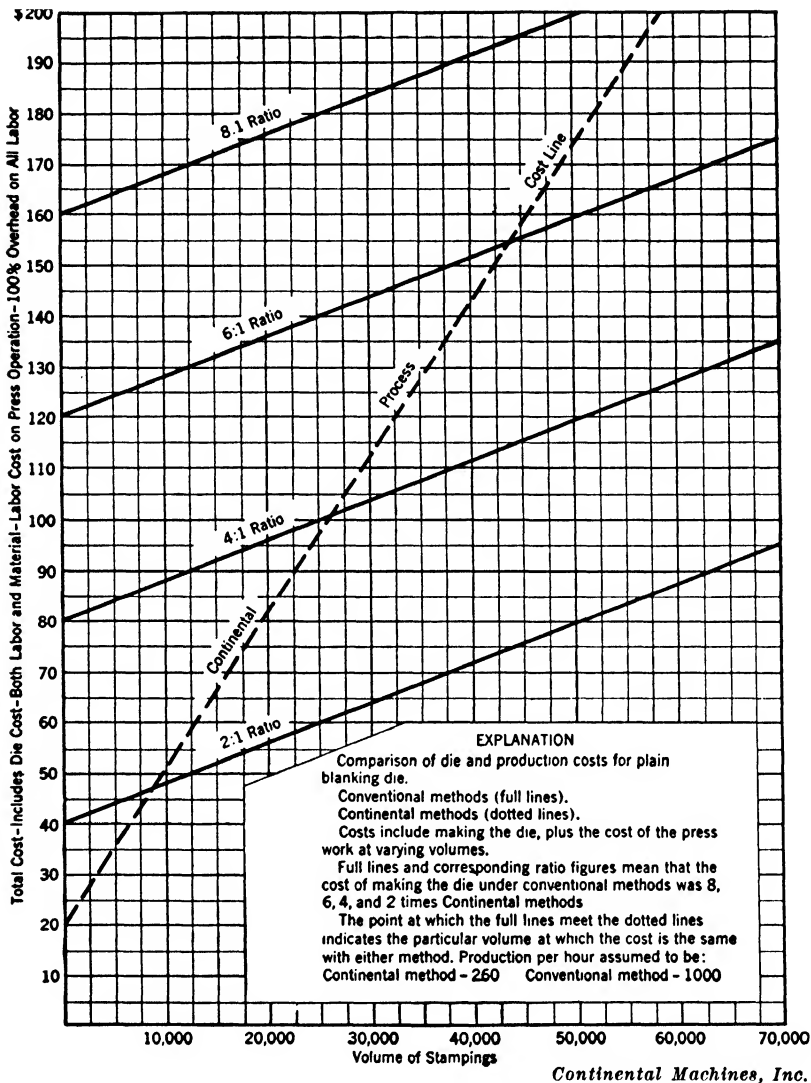
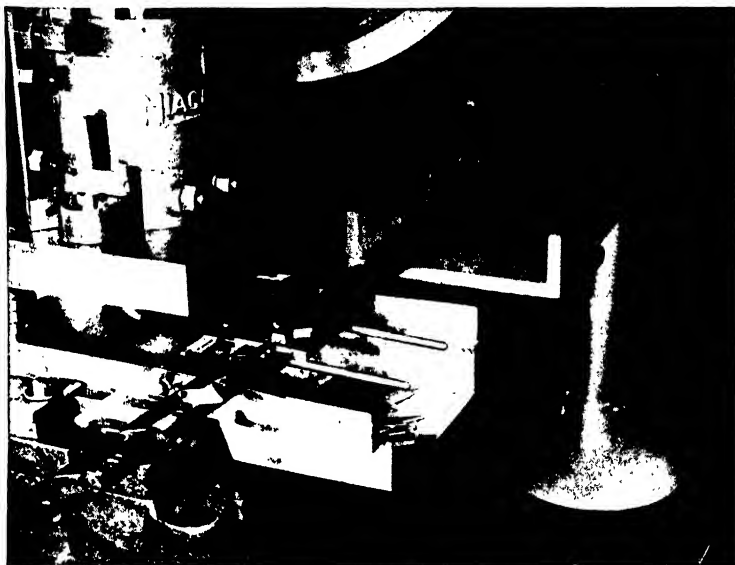


FIGURE 6. Cost comparison curves between conventional and temporary dies.

Note that these lines slope up more gradually because the punch press operation cost is less. The basis for this graph was taken as 1,000 per hour for each of the conventional dies and 260 per hour for the \$20 Continental die.

Though temporary dies are usually made to take care of short runs, they will be found to have a much broader scope in many applications. The graphic comparison shows that, with a ratio of die cost of only 4 to 1, the temporary die method is economical to use up until 25,000 stampings are produced in one run. With a ratio of die costs of 6 to 1 they are economical for a single issue of over 40,000 stamp-



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FIGURE 7. Turntable stock bench designed to allow stampings and punch, used in the temporary die, to drop into the bin when the pivoted stock table with attached die is pulled toward the operator.

ings, and so on up for the larger ratios of original die costs. If stampings are produced in smaller lots which would require resetting the dies more often, the temporary dies would have a greater cost-saving advantage because they have a much lower setup cost than the usual conventional dies.

The Continental Machines, Inc., advocates the use of a special device to speed up the operation of a punch press when temporary dies are used. Figure 7 illustrates the "turntable" stock bench as a universal fixture to operate the various types of temporary dies with speed and safety. It consists of a heavy cast-iron base and pedestal. At the top is a bearing so that the bench will swivel like a turntable. The operator moves the table back and forth with the handle. It will support a large weight of strip stock and work freely.

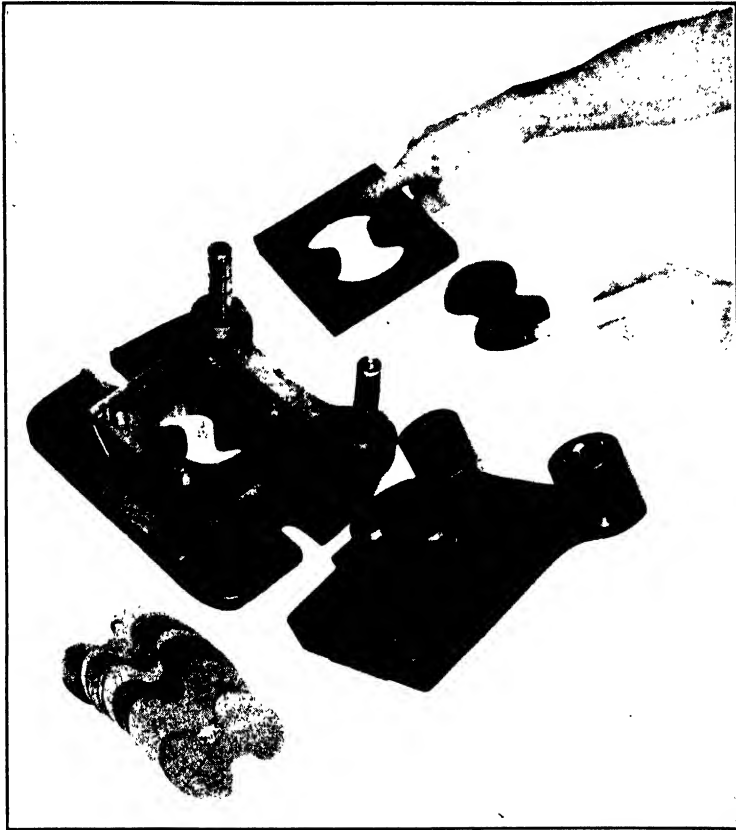
The operator never need place his hands into the press. The die is moved in and out of the press by operating the turntable stock bench, and all handwork is done out in front of the punch press.

PROCEDURE

1. A strip of the stock to be blanked is fed into the die.
2. The punch or punches are laid into the guide plate and onto the strip.
3. The die and punch assembly with the material in place are slid between the upper and lower hardened- and ground-steel die shoes.
4. The ram of the punch press is tripped and the die is slid forward over the two slide brackets. The finished blank and the punch or punches then fall into the catch pan.
5. The operator moves the strip stock forward into the die until he sees a "full blank." If the automatic stop is used the spacing is mechanical. He then picks the punch out of the pan and replaces it in the guide plate.
6. The die is then slid back between the two shoes and the operation is repeated.
7. The operator moves the die in and out of the press by taking hold of the handle on the turntable stock bench far away from the operating platens so that his hands are never placed in the danger area of the punch press.
8. All resetting of the stock and punches is done out in front of the punch press where the operator can see what he is doing.
9. Piecework rates may readily be established for this operation. Once an operator becomes accustomed to the motions, it is possible to complete the cycle in very little time. A test will show that the cycle may easily be completed in six seconds. Completing the cycle continuously will produce stampings at the rate of 600 per hour.
10. The die may be placed anywhere on the surface of the bottom platen. However, for heavy blanking it is preferable to place the die as near the center of the ram as possible.

The Continental Machines, Inc., makes a special metal-cutting band saw which is used extensively to speed up the production of symmetrical blanking dies. If the piece of tool steel used for the punch is over $\frac{3}{4}$ inch thick and if the toolmaker is skillful, both the punch and die can be made from the same piece. Figure 8 illustrates the completed tool with the blanks produced. Figure 9 shows how a small hole is drilled at the die clearance angle. The end of the saw blade is inserted through the hole. The ends of the saw blade are then butt-

welded to form a band saw by an attachment on the Do All machine. (See Chapter IX for more details of this machine.) The table of the machine is set at the clearance angle of the die and thus by sawing around the layout line on the die, the punch, when turned over,



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FIGURE 8. Conventional die made by method shown in Figure 9. Note portions of hole remaining at ends of fingers.

can be fitted to the hole in the die. Note the portions of the hole which are left as indicated by the pointing fingers in Figure 8. Dies which can use this technique can be made more quickly and more cheaply than when older methods are used.

Tool Standardization. There are certain types of tools or parts of special tools which can be standardized quite readily. Owing to the character of special tools, it is necessary to have a considerable number of parts which are unique and different. Nevertheless, certain

parts, such as hinges for box jigs, drill bushings, round punches, subpress die sets, clamps, handwheels and screws, and many other parts, can be standardized and made by ordinary machine operators. This

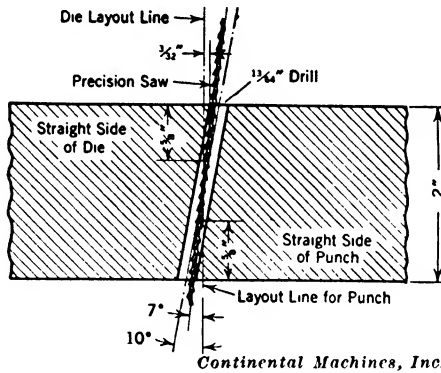


FIGURE 9. Method of sawing both punch and die from one piece.

is illustrated by the punch and die shown in Figure 10 in which there are only seven special parts out of a total of forty-eight.

Many tool rooms have the machines grouped by functions; that is, the lathes, milling machines, drill presses, shapers, and grinding machines are placed in groups. Generally, the grinding machinery is

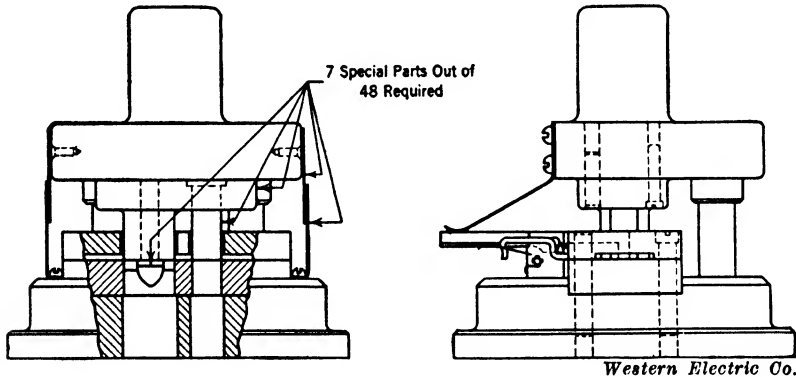


FIGURE 10. Standard "blank and piece" punch and die with only 7 special parts.

separated from the remainder of the shop because of the abrasive dusts. Jobs are distributed to key men in each of these divisions who in turn give them to the man best suited to the machining job. The men at the machines are high-grade operators capable of setting up their own work, but the men at the benches are master toolmakers.

The tool designer incorporates as many of such standard parts in the tools as possible and lets the expensive toolmakers do the fine machining, hand fitting, and assembly work. Tool costs have been



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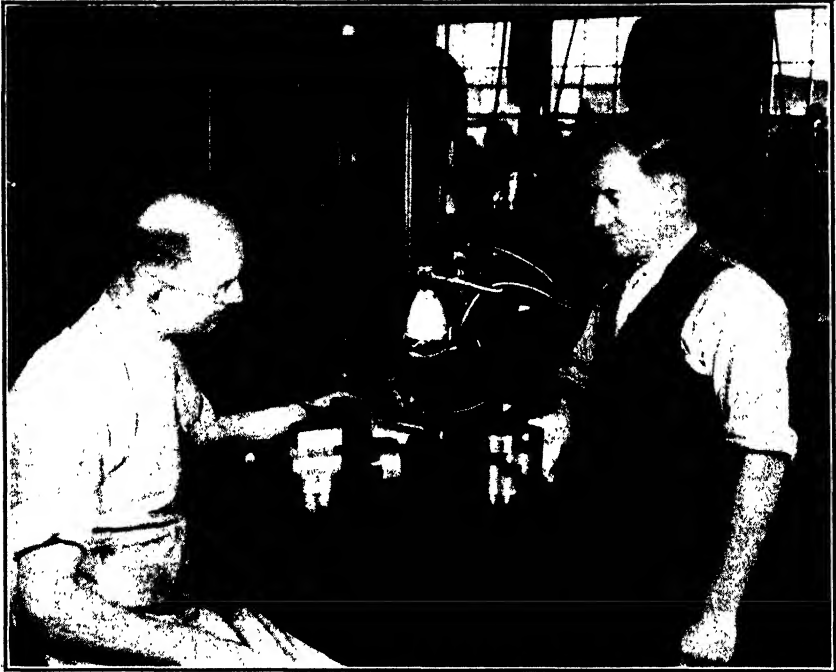
FIGURE 11. Method of sawing several jig parts from one piece.

reduced by such procedures without reducing the quality of the final job.

Wrenches, screwdrivers, drills, reamers, and other generally used standard tools can be standardized to cut down the number carried of any one size. The Detroit Edison Company made a study of machine reamers carried in stock and reduced the number from two hundred sixteen to thirty-two. The plan involved carrying only the types of any one size that were used to best advantage, and it also

meant reducing the number of sizes carried by designing parts with hole sizes changing only in $\frac{1}{16}$ -inch instead of $\frac{1}{32}$ -inch increments. Standardization of this type must be carried right up to the engineering design of parts, but it can be done.

Figures 11 and 12 show how the parts for a special jig were produced by the sawing process. The matched pieces as shown in Figure



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FIGURE 12. Pieces produced by sawing in Figure 11. Note saving of material by this method.

12 are made from one solid bar. The saving in cost is obvious over the conventional method of shaping each piece separately. Modern tool rooms are using every way possible to speed up the production of special equipment and tools and thereby reduce the cost.

In practically all industries which use special small tools, these tools are designed or specified by the user's designers. Not all these tools, however, are made in the user's tool rooms. Some plants make and maintain all their special tools, while others have all tools made by established shops and only maintain the tools in their own shops.

Standard tools, such as drills, taps, saws, and reamers, made on a production basis by regular tool manufacturers, are usually better

grade and cost less than those made in limited quantities in the user's shops. Moreover, if a reputable manufacturer sells a tool that is imperfect because of flaws, improper heat treatment, or incorrect size, he will usually replace it without cost. When a company makes its own tools, such imperfections are losses within the business and cannot be recovered. Specialized equipment, standard materials, and good methods usually produce better drills, taps, and reamers than the occasional standard tool made by the user.

Tool Performance Records. Tests of various standard tools should be conducted from time to time to check the performance of different manufacturers' products. These tests should be made under controlled conditions where all the facts can be obtained by unbiased observers. Such data are valuable in discovering improvements in new designs and also in testing the claims of optimistic salesmen before the new tools are actually placed in the shop. In addition, a record of the performance of tools under normal shop conditions should be kept to determine actual tool costs per unit of product. Many concerns keep a card file to show the tool number and material for each special tool along with an identification of the part produced by the tool. A cumulative record of pieces produced is kept until the tool fails. Accurate tool costs are obtained by this method and improvements in materials, design, and workmanship can be noted and economically justified or condemned.

Central Tool Sharpening. Workmen in production departments in general should not be permitted to sharpen their own tools or to check their own inspection gages. Generally there is one way in which a tool should be ground; the various clearance and rake angles have an influence on the life of the tool, the finish it produces, and the power required to cut the chip. This is particularly true with the new cemented carbide tools which must be ground within close limits to perform well. Each workman has his own ideas and limitations, either of which can alter the tool from the correct shape and thus cause trouble. In job shops where more highly skilled men are usually found, the single-point tools are sharpened by the mechanics on the job, but even here performance varies widely from the best to the worst tools in the shop. The best-controlled shops have central grinding rooms adjoining the tool cribs where tools are properly conditioned for the workmen. Tools are issued in wooden blocks or boxes designed to hold enough for at least one-half day's work. As the dull tools are returned, a new supply of sharp ones is released for the next period.

This plan has advantages not immediately apparent. In addition always to having the correct predetermined shape, the number of tool bits in the total shop inventory can be much fewer, and the machine can be producing a greater part of the time because the mechanic does not need to take time out to sharpen the tool himself. Anyone who has ever noticed the large number of different-shaped tool bits in a mechanic's tool box under the old scheme can readily realize the saving in tool steel inventory the central grinding would make. Since the grinding is usually done by special tool-grinding machines, the cost per tool is less than when each man is allowed to grind his own by hand.

Tool and Gage Inspection. In addition to the usual better performance of cutting tools which is a direct result of centralized grinding, there is an additional advantage of periodic inspection. Tool bits, milling cutters, arbors, and gages should be inspected when they are returned to the tool crib. The types of inspection may run from a cursory examination to determine general condition to a rigid check for size to within tolerances of 0.00001 inch in a special temperature- and humidity-controlled room.

For the general guidance of the tool crib operator, a table or chart showing what to look for and how to do it should be posted in a conspicuous place. Figure 13 shows inspection directions for a variety of tools.

Each type of tool stored in the crib should have periodic inspection by the attendant. This inspection for certain classes of tools can be made at the time the tool is brought back to the crib. Many of the visual inspections can be done while the tool is being placed in its bin or storage place. In a shop with long runs or in line production with accurate work and close tolerances, the gages are often checked once or oftener per day to prevent spoilage due to improperly set gages. If gages are dropped or bumped very hard, their accuracy should be questioned until they can be inspected. Predetermined tolerances must be checked and adjustments made when necessary. When the workman knows that gages are seldom checked or when he knows that adjustment screws are not sealed, it is possible to cover up mistakes in machining by claiming that the gages furnished him were not properly set.

In careful, well-organized plants, a regular plan is set up for frequent inspection of the places in tools where possible trouble occurs. For instance, an end mill cutter should be examined when it is returned to the tool crib for depth of flutes (if teeth have been repeatedly sharpened, the flutes become too shallow to carry the chips away),

for sharpness of teeth, condition of taper and tang (or internal thread on taper end, if mill is held by draw bolt), and for missing teeth. These visual examinations can be made while the tool crib attendant is placing tool in its proper bin. If anything is wrong, the tool can

TOOL INSPECTION CHART

Type of Tool	Inspect for	Method of Inspection
Arbors	Scratches parallel or at right angles to axis, bad centers, undersize, bent	Test size with a gage or micrometer. Test for bad centers, scratches by visual means. Test bent arbors on pair of centers. Should be checked when returned
Gages	Size, accuracy within prescribed limits	For small tolerances, say 0.0001-inch test with precision gages. If adjustable, gage should be sealed after adjustment. Check daily
Milling cutters	Sharpness, size, and condition of cutter	Sharpness by touch, size by gage or micrometer, condition by eye or hardness tester
Dies, punch press	Sharpness of die and punch, condition of die, size	Inspect sharpness and condition of die by visual means. Due to taper in die, size of flank changes when die is sharpened, check size and condition after use
Dies, drop forge	Condition of die, size of forging	Check forging for size after each 1,000 pieces produced. As die wears, forging gets larger and requires more metal for good forging

FIGURE 13

be placed on the repair bench where it can be repaired before it is put away.

Storage Facilities. The tool crib of even a comparatively small metal-working shop must carry hundreds of items. The International Business Machines Corporation reports ¹ about 60,000 tools, including jigs and fixtures, and about 15,500 punch press dies, which are kept in

¹ *American Machinist*, Vol. 81, p. 554.

the main tool crib or storage. The task of keeping this large number of tools ready for service and knowing where they can be found quickly means that a definite system must be developed and carefully used. (See Figures 14, 15, and 16.)

Any system of storing, issuing, inspecting, or maintaining tools must be subordinate to the main job of production. All portions of the productive plant must be served adequately with the proper tools with



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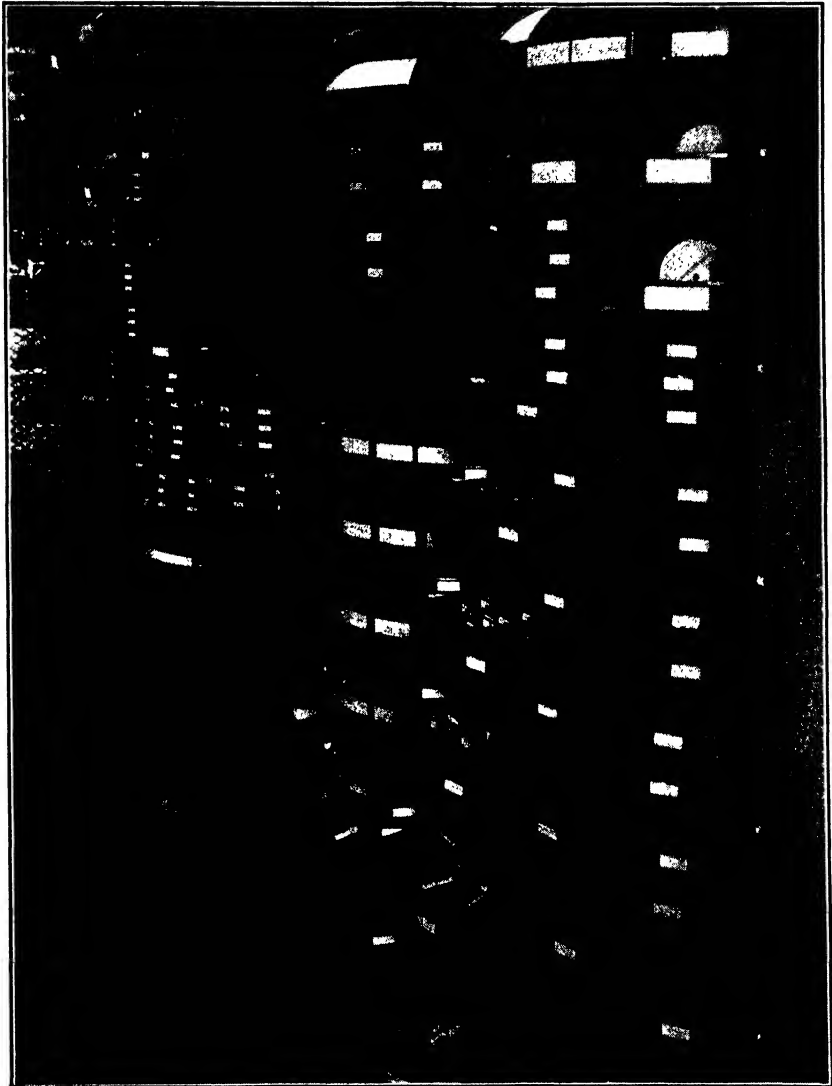
FIGURE 14. Tool crib window.

little or no delay for the production centers. Too often shop executives fret about the wasted wages of waiting mechanics or workmen when the wasted productive capacity of the machine is usually more important. Since overhead costs often are more than the labor cost, the waiting for tools to be delivered and the loss of time caused by tools in poor condition can become quite expensive.

Many methods have been devised for the operation of tool cribs, yet none can be called the perfect plan for all situations. Within the same plant there may be several systems in use because of the service demanded.

Job shops or departments seldom can allow each workman to have enough tools to do the average run of jobs through the plant. However, some companies with more or less loose systems have found workers' tool boxes, bench drawers, lockers, and sometimes basement

home workshops with hundreds of dollars' worth of various small tools. Tool inventories become high because the men forget tools which may

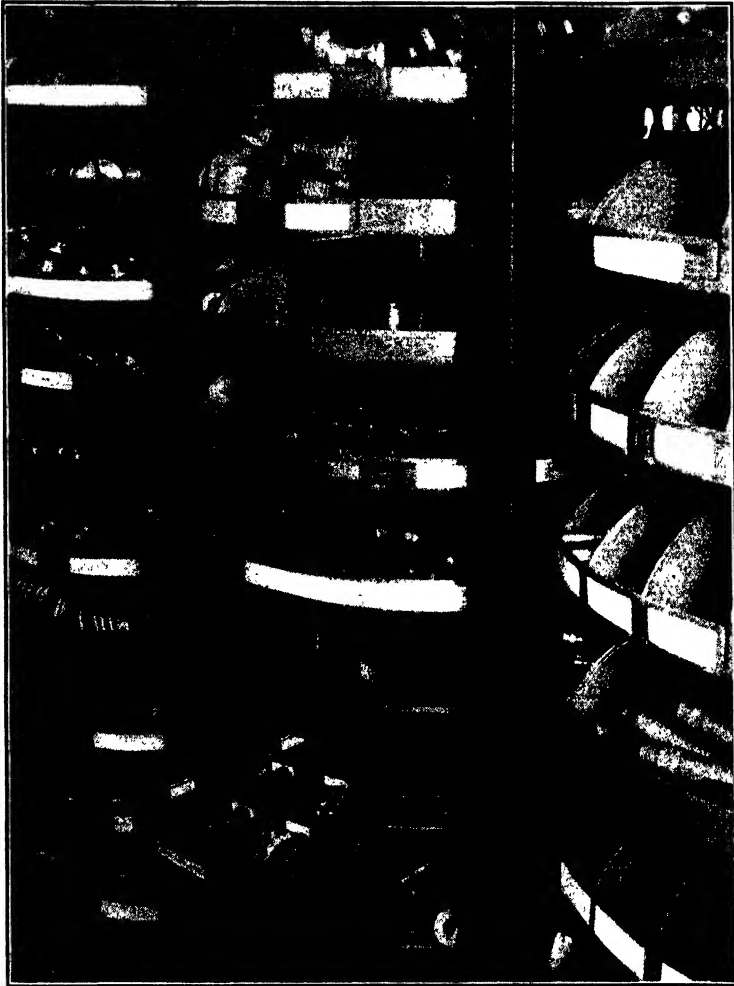


International Business Machines Corp.

FIGURE 15. Rotabin method of storing tools.

be stored in unusual places and go to the crib for duplicates of these tools. When a company treats tools so lightly, the men become careless also, and tool costs mount higher and higher.

Often one man's job may be held up for lack of the proper tool which is in another worker's locker or tool drawer. A good, double-check system can largely eliminate this difficulty. To have tools



International Business Machines Corp.

FIGURE 16. Rotabins allow quick access to tools stored in small space.

available when needed without running the tool inventory too high, it is wise to have a good mechanic with executive ability in charge of tool cribs.

Plants with a production control system have the planning department issue the manufacturing orders complete with all the operations

listed, the machines to be used, the tools to be used, and the scheduled time the various operations are to be started. A copy of this order is sent to the tool crib in advance of the scheduled date so that the tool crib personnel can accumulate all the tools on or before the scheduled time. The manufacturing order sent to the tool crib is filed for attention on the scheduled date. On this date, unless the tool crib attendant is notified to the contrary, the tools are delivered to the proper place, usually by the move men who handle the internal transportation of other materials. (See Chapter XXIV.)

TOOL CLASSIFICATION

When tool crib attendants are charged with providing adequate tools for production with a minimum waste of the mechanic's time, they must be able to find the tools readily. Several tool classification systems may be used to list the various items carried in the cribs. Tools can be classed by function, such as boring, drilling, reaming, and tapping tools, measuring tools, and milling cutters, with each function represented by a letter, a number, or combination of both if there are different kinds of tools. Unless the tools in any functional group are incompatible in size or other characteristics, they may be stored within a close area with subclassifications to aid in finding a certain unit. A main classification such as chisels would include cape, cold, chipping, air hammer, wood, and paring chisels, with subclassifications involving size and shape of the cutting edge, size of shank, and difference in keenness of cutting edge.

Due to the tremendous variety of tools, it is absolutely essential to have some well-known classification system in operation to enable the tool crib attendant to locate any tool quickly.

Identification of Tools. There are three primary methods of identifying tools which at the same time can be used for indexing and locating them in the tool cribs. These three systems are also used in a large number of combinations in various plants.

1. Straight numerical system.
2. Classified numerical system.
3. Letters or combination of letters in either a meaningless or suggestive manner.

The straight numerical system is often used, but it assumes a variety of forms. In some plants producing regular products, part numbers with letter suffixes are used to identify tools belonging to a particular operation. Other plants simply number tools in a consecutive manner, sometimes with a *T* prefix to denote tool number. Such

numbers have no relation to the part number. The first system mentioned tends to drift into the second if the old tools are used when the part number is changed or if the same tools are used for several part numbers. Under both systems, although the numbers will identify the tool after it is found, it is not always convenient to provide groups of compatible tools with consecutive numbers for ease of storing and classification when they are wanted quickly.

The well-known Dewey decimal plan has been used for tool identification, and it can be carried as far as necessary to differentiate any small difference, but it may fail in the early divisions because only ten variables can be used in any group. To get a fine division, it is often necessary to have a number of digits which make the recording and remembering of them difficult.

The mnemonic system consists of a series of letters designed to suggest the article. A system for indicating letters to suggest the various classifications was worked out by the late Frank B. Gilbreth for metal-working shops. The *Cost and Production Handbook*⁸ illustrates how an external, adjustable-limit gage of the caliper type can be described by the mnemonic symbol MGCELA. The first designation assigns the tool to a broad general group.

M	measuring tools
MG	gage-type measuring tool
MGC	caliper-gage-type measuring tool
MGCE	external caliper-gage-type measuring tool
MGCEL	limit, external, caliper-gage-type measuring tool
MGCELA	adjustable-limit, external, caliper-gage-type measuring tool

If the size limits, say 5 to 5½ inches, are added to the symbol MGCELA, the tool is completely described in a unique way by a symbol which in time can become a shop language. The system is capable of almost unlimited expansion to provide unique classification for all types of tools. New tools can be fitted into their proper places in the scheme without disturbing the previous symbols of older tools. Even if the letters O and I are left out because they may be mistaken for figures, the mnemonic system has possibilities of twenty-four classifications for each breakdown whereas any numerical system has only ten. In addition, the letter symbols taken from charts such as shown in *Cost and Production Handbook*⁹ can mean only one thing to all persons.

⁸ L. P. Alford, Ronald Press, 1934, pp. 824-827.

⁹ *Idem.*

Every tool should have its symbol or number distinctly and permanently marked in a conspicuous place. When the tool is not tempered or when the marking method will not destroy inherent accuracy of the tool, the mark can be stamped by numerical or letter die stamps. These symbols should be at least $\frac{1}{4}$ inch high for ease in reading. Acid etching or electric arc burning are commonly used for fragile or hardened tools. The symbols or numbers should be placed in positions where they can be read with the minimum effort. Often, a flat spot ground in a uniform and conspicuous place on tools will offer a better place for the mark where the normal usage of the tool will not destroy it and where everyone knows the mark's location. Marks on all tools should be as large as possible because lighting conditions are not always the best in all portions of the shop and tool cribs.

In addition to marking tools for kind and size, it sometimes is desirable to have some system for quickly identifying tool material. It is disastrous to assume that a milling cutter is made from high-speed steel if it is actually made from carbon steel. One suggested system¹⁰ uses paint of a different color applied to a nonworking surface of such tools as milling cutters and drills which immediately designates¹¹ the material as shown below.

MATERIAL	COLOR
High-speed steel, new	Green
High-speed steel, recut	Yellow
Cobalt high-speed steel	White
Tungsten high-speed steel	Orange
Carboloy	Red
Stellite J.	Blue

The storing and issuing of tools can be simplified with the mnemonic system. Mr. Gilbreth stated, "All tools that are alike shall be together, and those that differ by one variable only shall be contiguous." An area of the tool crib is dedicated to a certain general class of tools. Certain shelves, floor areas, or bins are reserved for a given subclass, while further subclasses are placed in separate bins, trays, rotabins, or other devices in alphabetical order. Figures 14 to 16 illustrate how tools are stored so that they are readily available in tool cribs of the International Business Machines Corporation.

Locating the Tool Crib. In general, tools are either stored in one large centrally located tool crib or in one or more branches of the main crib located at convenient points in the plant. Sometimes each of the branch or smaller cribs are independent units with a complete

¹⁰ *American Machinist*, Vol. 81, p. 506.

¹¹ This scheme can be expanded to fit any group of tools used in any plant.

set of tools, but more generally they are a part of the main tool crib where the only complete list of tools is kept. If unusual requests are made at the branch, the main crib loans out the tools upon requisition from the branch crib. The process can be compared to the main library and its outlying branches in any large city.

The type of product, size of plant, method of manufacture, number of tools required, and skill necessary on the various operations all have a part in deciding whether to use one central or several branch cribs. Certain industries like flour milling, cement, baking, and meat packing neither use a large variety of tools, nor do they change the tools often, for producing the product. One centrally located crib could serve such industries well. Likewise small plants, even in the metal- and wood-working fields where tools are numerous, could easily get along with one crib. Even in large industries, where distances are not too great for electric or other power transportation trucks to travel economically, one large tool crib can serve where jobs are carefully planned in advance and where tools are delivered from the tool crib to the proper machine at the proper time.

Branch cribs are indicated when a variety of products requiring a number of tools are made in widely scattered departments. When it is the policy of the company to have workmen get their own tools from the crib, it is uneconomical to have the men walk too far for their tools. A balance between value of time lost ¹² in walking to and from and waiting at the tool crib should be made against the cost of maintaining another crib. Inventory and storage costs for most tools will run rather high and an economic balance should be made before deciding on the tool crib policy.

By laying out a plant which produces several products so that the machinery departments, which generally use the most tools, are located with the tool crib in the center of the greatest activity, it is possible to issue tools from all sides of the crib and thus possibly avoid branches.

Factories employing semiskilled labor on machines have a more serious tool problem because this type of labor does not appreciate the cost and the limitations of fine tools. Special precautions should be taken to safeguard the company's investment by educating unskilled and semiskilled workmen to use tools properly.

When tools are stored by groups, such as drills, reamers, milling cutters, shovels, and nozzles, the group used most frequently should

¹² This lost time affects both labor and machine overhead cost, which together may be several dollars per hour.

be stored near the issue window. Sometimes the frequency of use changes and it is desirable to be able to move a group section. One firm placed six double-wheel casters on each of the welded-steel tool racks to make it easier to rearrange them when change was desirable. It seldom is desirable to store tools more than 6 feet high. It is better to have lower ceilings and more floor levels to get better vision and selection of the tools quickly.

TOOL CRIB PERSONNEL

Tool crib personnel includes in the largest sense tool inspectors, record clerks, and window attendants. All these men should be carefully selected for responsibility, honesty, and respect for fine tools. If any tool crib workman carelessly tosses a micrometer or any other fine tool on a bench he should be reprimanded, and if he persists some other less-exacting job would be better for him. Small tools are readily carried away in pockets and lunch boxes. Such pilfering can best be stopped by having an honest tool crib staff and by allowing no unauthorized persons in the tool cribs.

Methods of Getting Tools to the Workmen. The institution of tool cribs in any factory is for the purpose of tool control. It tends to reduce the inventory cost, to provide better tools through regular inspection, and to care better for the tools by careful storing methods. But it must not be forgotten that tools are purchased to aid and promote production, which means that the tool crib must be organized to get these tools to the machines as quickly and as easily as possible. There are three ways in common use to distribute tools to workmen in any plant. Each method has advantages under certain conditions and, generally, after critical examination of the job conditions, it is found that all three methods can be used to advantage in many plants.

1. Allow each workman to call for tools at issue windows.
2. Allow each workman to have a complete set of necessary tools to be kept until he leaves the company's employ or until his job is changed.
3. Deliver all tools as needed to machines according to a predetermined plan generally administered by the dispatchers. (See Chapter XXIV.)

The first method is commonly used in shops where production control methods are not used. Time spent by the workman in getting tools means loss of money in both labor and overhead expenditures, since neither the man nor machine is producing during the process of procuring tools. Moreover, when the mechanic gets to the tool crib

window, the tool he seeks may be out, broken, or otherwise not available. Further loss to the production schedule occurs, and costs mount higher until another job or another tool can be found.

It usually is necessary to allow the workman to get his own tools for emergency jobs or for maintenance work. It is quite common to have toolmakers get their own tools or to have them send apprentices or messengers to get the tools for them.

The second method is commonly used when men are on repetitive jobs requiring the regular use of a few tools. Line assembly men of a mass-produced article are furnished with a kit of tools containing the wrenches, screwdrivers, and drifts required to do the regular job. Any special tools required for occasional jobs or emergency use are withdrawn from the crib when needed. Meat-packing plants furnish each man with the knives needed for the man's position on the conveyor line or production center. It is true that this method eliminates lost time in getting tools from the crib, but tool inventory costs would overbalance the saving if any great number of expensive tools were furnished to each man.

The third method is designed to have the good features of the first two methods, but it has developed some disadvantages of its own which must be considered. Not all businesses or all jobs in any business can be pre-planned to the point where it is definitely known just what tools will be needed or at what time they will be needed. However, if good production control methods can predict the performance of a department, then tool lists can be pre-planned and tool crib personnel can be notified when tools are needed. Then the tools can be delivered to the point of use at the proper time by cheaper labor than the mechanic on the machine. When the job is finished at the production center, the tools can be returned by the transportation system. By this latter method, men and machines are kept at the main job of producing the product.

Regardless of the method used to issue the tools from the tool crib, the workman should be charged with the tools he receives. This record is for the purpose of knowing where the tools are, who is using them, and how long they have been out of the crib.

Single-Check System. The single-check system is commonly used but it has many weaknesses. The workman deposits his check for any tool withdrawn. This check is generally hung on a peg adjacent to the space the tool occupies. If the workman quits, he must turn over the original number of checks issued or pay some small sum, say 50 cents, for each one lost. Since it is difficult to look over a large tool crib for possible lost checks, the workman may know this

weakness and withdraw expensive tools for his personal gain before he quits, paying only the 50-cent charge if the check cannot be found. During the rush hours in a tool crib it is possible to knock off checks which may be replaced on the wrong hook. Confusion or even heated arguments often arise from such mistakes.

The single-check system is best suited for small cribs which store no really expensive tools or which serve only a limited number of workers.

Tool Order		
Payroll Number <u>816</u>	Tool Number <u>T12</u>	
Work Station No. <u>11</u>	Date <u>6-8-42</u>	
Quantity	Size	Kind of Tool
6	1/4"	Drill
Signed <u>John Doe</u>		
<small>This order is good for one kind of tool only. Workmen must return triplicate with tool.</small>		

FIGURE 17. Triplicate method, tool crib check.

Double-Check System. Checks similar to the above method are used for the double-check system. When the workman asks for a specific tool, his check is hung on the tool's location peg and, in addition, a check showing the tool number is taken from the tool location and hung on a peg bearing the workman's number. At any time, then, it is possible to glance at the peg bearing the workman's number to find the number and kind of tools he has checked out. The double-check system takes very little more time to administer than the single-check system, and it saves all the time spent searching for lost checks when trouble appears.

Written Forms for Withdrawal of Tools from Tool Crib. Written forms are sometimes used to withdraw tools from the cribs. Each time an operator wants tools from the issue window he writes out a tool order in triplicate, similar to Figure 17. The workman retains the triplicate until he returns it with the tool, the original is filed against the workman's number peg, the duplicate is filed at the tool

location peg. Upon returning the tool, the workman also returns his triplicate copy which is destroyed by the tool attendant, while at the same time the workman is handed the original which he destroys. The duplicate can be saved for filing in a suitable place under the tool number so that records of tool use per month or other similar records can be compiled periodically if they are useful.

QUESTIONS AND PROBLEMS

1. Describe the tool and explain the function of eight different kinds of common dies.

2. Name twenty families of small tools which are used in industry.

3. Describe the special small tools used in an industry not mentioned in the text.

4. Does the use of small tools always reduce the cost of production? Why?

5. How much can industry afford to pay to carry castings by hand up two flights of stairs (24 feet)? The castings weigh 25 pounds each. A continuous elevator, platform type, costs \$2,500 and uses 60 per cent of the energy supplied. Electricity costs 2 cents per kilowatthour. Fixed charges on the machine average 20 per cent per year.

6. Write a brief justification for making a new tool pay out of its estimated savings for any unamortized value of the replaced tool.

7. Part L5362, a regulator body of which 15,000 units are required per year, has been made from a gray iron casting. Castings cost \$10 per 100 pieces. Shop scrap has been 0.5 per cent. Machining labor is \$4 per hundred pieces. Machine shop overhead is 150 per cent. The tool cost including the metal pattern for the gray iron casting was \$150 ten years ago. It is proposed to make the part by stamping if feasible. The dies and other tools to produce this part from sheet metal are estimated to cost \$1,600. The material for stamping will cost \$3.25 per hundred pieces. Labor cost is \$4.22 per hundred pieces owing to some brazing required. Overhead remains at 150 per cent. Fifteen thousand units per year will probably continue indefinitely. Can the stamping method be justified if the stamping tools will produce 250,000 units before they are worn out?

8. Part 5375, a lever arm, which now is a bronze casting, is produced at the rate of 15,000 pieces per year. Labor cost for machining the lever is now \$2 per hundred. The material cost is \$5.12 per hundred. The burden in the shop is 120 per cent of direct labor cost. Tool costs for this lever now have no book value. Zinc base die castings have been proposed but the dies cost \$320. Material costs would be reduced \$2.30 per hundred pieces. Labor cost would be reduced \$1.85 per hundred pieces. The burden will be the same on direct labor. Can this expenditure for tools be justified in twelve months?

9. Tools estimated at \$411 are necessary to reduce the cost of assembling part 5334 to part 5280. These proposed tools would reduce the labor cost \$3.14 per hundred pieces. The assembly is needed to complete 21,000 final assemblies per year. The demand is stable. The burden is 80 per cent in this department. Can the expenditure be justified?

10. How can shop foremen and mechanics contribute to better tool design and operation?

11. Should machine designers know the fundamentals of tool design? Why?

12. How does the quantity to be produced affect tool design?

13. Decide whether to use a temporary die or other means to produce only 2,000 pieces of the part shown in Figures 4 and 5.

14. What are the disadvantages of a metal-working plant's making its own taps?

15. When should tool performance records be kept, assuming that they more than pay the cost of compiling them?

16. How can standardization of tools reduce costs?

17. What types of tools need periodic inspection and under what conditions should they be inspected?

18. How and why would you install a central tool-grinding department?

19. Devise a tool-issuing system for a metal-working shop producing three models of washing machines, production about 60,000 units from all models. Practically all parts are made in manufacturing lots or batches at the proper time.

20. What system of tool classification and identification would you use in a plant which manufactures heat regulators? About 20,000 different parts are used with many thousands of all classes of tools needed to produce the parts.

21. When are branch tool cribs necessary? How can they be avoided to some extent?

22. Describe several methods of checking location of tools being used in the plant. How well does the single-check system do this?

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CHAPTER XI

ROUTING, OPERATION SHEETS, AND INSTRUCTION CARDS

The procedures, analyses, and thought processes described and discussed in Chapters VIII, IX, and X are necessary before final decisions can be reached on the methods to be used for producing the product. The ability of the plant's factory organization to engineer the production of the required quantity and quality of product, at the proper price, and within a predetermined interval of time, must be equal to the ability of the plant's design engineers to do the original job of designing the product. The engineering for production involves a thorough analysis of all the processes and methods that might possibly be used for the product. These preliminary studies at their best include techniques for planning and recording each step used for each separate operation in an effort to avoid difficulties and disappointments after the job is started in the shop.

Routing as an Element of Control. The function of routing is intimately associated with product analysis, the tools used, and the subsequent planning for the product in the shop. Routing includes the assignment of a definite sequence of operations, the selection of the proper machines or production centers with adequate tools specified, and sometimes the specification of the proper personnel to do the work. The net effect of these decisions is to determine the shortest and most economical path that each part is to follow from the time it arrives as raw material until it leaves as finished product.

Effect of Method on Routing. The routing is necessarily closely related to the job and the method to be used. There are usually many different methods for doing the same job. A given flat surface on a small casting may be finished by hammer, chisel, file, and scraper; by shaper or planer; by facing in a lathe or milling, by disk or surface grinding, sometimes by coining procedures, and by broaching. Any or all of these could be used in some shops, depending in a large measure upon the number of castings and the availability of a particular machine when the castings are needed.

The surfaces produced by most of these methods may eventually have about the same degree of excellency, but the time to produce the same quality by the different methods would vary widely. Natu-

rally, good routing, then, would utilize the best methods available under current conditions. However, scheduled machine loads (discussed in Chapter XXII) sometimes make it necessary to use the second best method when the most economical machine is unavailable. Instead of holding up production by waiting until the best machine is available, it may be better to use a slightly more expensive method and still keep delivery promises.

Effect of Product and Plant Design on Routing. The routing of parts through the shop involves thinking in advance, which differentiates modern production control from the simple production department. Some types of manufacturing are quite simple and require practically no routing procedures after the plant is designed and built. The paths of Portland cement, flour, bread in a mechanized bakery, and many other products through their operations are often fixed by the plant design and machinery layout. Since products of this type are seldom changed, the routing function can almost be forgotten after the machinery layout is completed.

Products such as automobiles, radios, and other mass-produced articles, which have periodic model changes, also have a minimum of routing to do for current work going through the plant. However, such plants plan their operations and routing with the greatest care at the time the models are changed. It is not unusual to begin the planning and routing for new automobile models many months before the model is ready for the public. Each change caused by the new model is analyzed in detail. The effect of any change on the layout of machinery, equipment, conveyers, and other means of transportation is studied and recorded on scale drawings for each department affected. Just before the model changes are announced to the public, the production facilities for the old model may be closed down to allow the new layout to be completed with a minimum of confusion.

Thus the routing of the parts is fixed by following the production line as it was planned in advance. Straight-line production, as this is called, means a minimum of transportation as the parts move from one production center to the next one adjacent to it. A heat-treating furnace may be preceded in the line by a broaching machine which in turn is preceded by a multiple-spindle drill press. A sequence of operations is selected that will do the best job, and the machines and equipment are brought in line to carry out that sequence.

Only a few parts which are required occasionally for special or custom purposes, such as right-hand automobile steering gear and linkage for foreign service, special keyboards for typewriters or an extra-fine tone quality for a radio would require special routing in-

Routing for Job Shops. The ordinary job shop, if it is to do a good job of production control, must route each new job as it is released to the shop. The preliminary study usually begins after the sales order has been received unless, for speed, the design room releases advance information. The blueprint or specification for each part

R-1406

Pump _____ SHOP ORDER *IN-166-1-2-3-A*

Quantity *4* Part *Spear Case* **B No. 4700**

Pattern No. *P-1417* Drawing No. *A-1402-A* Code _____

OPER NO.	DESCRIPTION	OPERATOR	SCHEDULED		DEF	SPOIL	COMP	ASSIGNED TO MACH	MOV'D
			START	FINISH					
<i>2</i>	<i>Face flanges</i>							<i>6-3</i>	
<i>3</i>	<i>Drill flanges</i>							<i>4-5</i>	
<i>5</i>	<i>Mull and bore</i>							<i>6-3</i>	
<i>6</i>	<i>Drill and tap</i>							<i>4-5</i>	

Mat'l Spec'd _____ Date Avail. _____ Date to Shop _____
 Mat'l Ret'd to Stock _____ Usable _____ Def. _____ Spoil _____ Ent'd Records _____

FORM A - 43

forming an operation but to list any possible alternates that may be used as second or third choices. This allows flexibility for the machine load if too much is scheduled for the first-choice machine. If the load scheduled for the best equipment is too great, the job may be subcontracted to meet the schedule.

The selection of the machine for a job shop is often influenced by the comparative cost of setting up for the job. In many instances, a general-purpose machine requiring little setup is preferable to a special-purpose machine requiring a complicated setup.

Routing for job shops is often hand written on a simple prepared form such as shown in Figure 1.

Routing for Regular Production. The routing procedure for products manufactured regularly is no different from the job shop variety except that it is done more deliberately and carefully. Methods are more carefully selected for economical manufacturing, more elaborate tooling is specified, and the design is critically examined for possible changes to reduce cost. In other words, since the product is a continuing one, any savings to be made by a complete study of the selected manufacturing procedure will continue as long as the product is made. The techniques discussed in Chapters IX and X should be the basis for determining the methods, tooling, sequence of operations, and other information normally included in the operation sheet for such part.

OPERATION SHEETS

The routing instructions for the production shop are usually written on a form which may be called an operation sheet, a manufacturing layout record, an operation schedule, an instruction sheet, or a shop order. (This book will use "operation sheet.") All are used for essentially the same purpose—to provide official information for the manufacture of the plant's products. The information is compiled after careful consideration to find the best way to make each unit. These sheets then become as basic as the blueprints or specifications; they show how and where the products are to be made, whereas the prints or specifications show what the product must be *after* it is made. There can be no fundamental conflict between these two main sources of manufacturing information since each is dependent on the other although supreme in its own field.

It is impossible to give detailed instructions for preparing any one operation sheet. The men who decide on the methods, the sequence of operations, and the route a product follows in a factory must know the product, the shop, the possible auxiliary tools and the various

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methods used in the industry. This is not an easy task and each shop must train its own engineers to do a good job. An economic check must be made at many points to be sure the right procedure is under consideration. This text cannot teach what to write on an operation sheet, but it can approach the problem by stating the type of information which should be included. The forms shown are merely illustrative and should be changed to suit local conditions.

Part No. <i>PJQSR</i>		Drawing No. <i>11481</i>		Date <i>4/7/39</i>	Written by <i>R.S.V.</i>
Part Name <i>Back, 3" Heavy Duty Padlock</i>					
Lot Size <i>30,000</i>		Material <i>SV .083 x 2 15/16 SCR</i>			
Time per Piece, Hours	Setup Hours	Operation		Machine Number	Tool Number
		Number	Description		
		<i>1</i>	<i>Blank & File (Together with P 2 1/2 H S M)</i>	<i>PA 17</i>	
		<i>2</i>	<i>Form & Stamp To Process Stores</i>	<i>PD 7</i>	
		<i>3</i>	<i>Pierce</i>	<i>PD 9</i>	
		<i>4</i>	<i>Straddle Mill Shackleyway</i>	<i>MP 5</i>	
		<i>5</i>	<i>Rumble in Sawdust</i>	<i>T 2</i>	
		<i>6</i>	<i>Grind Burrs on Top</i>	<i>G 7</i>	
		<i>7</i>	<i>Punch Shackleyway Heel</i>	<i>PH 4</i>	
		<i>8</i>	<i>Punch Shackleyway Nose</i>	<i>PH 5</i>	
		<i>9</i>	<i>Planish Shackleyway</i>	<i>PD 22</i>	
		<i>10</i>	<i>Trim To Process Stores</i>	<i>G 4</i>	
		<i>11</i>	<i>Rumble in Sawdust</i>	<i>T 2</i>	
		<i>12</i>	<i>Sandblast</i>	<i>X 8</i>	
		<i>13</i>	<i>Ebony Black Rustless Finish To W. M. Storrs</i>	<i>X 11</i>	

FIGURE 2. Simple operation sheet.

In some plants where small job orders are sent through the plant only once or twice, the operation sheet can be a very simple form, such as shown in Figure 1 or 2. The time for each operation and setup may often be estimated. If the job has been in the shop before, time studies can be entered on the operation sheet but generally short runs are estimated for scheduling purposes. (See Chapter XII.) Space should be included for machine and tool numbers where they are used.

Methods of Designating Operations. Several systems are now used to number the operations so that each will have an official number to be used for all records and controls throughout the plant. Standard operations can be designated by numerals from 1 to 100. If additional operations are inserted from time to time they may be placed in their proper sequence and given a number, say 8A, if the additional

work follows operation 8. Another method of doing the same thing is to use number 10 for the first operation, 20 for the second, etc. Thus when any additional operations are inserted between the original first and second, they are numbered 11, 12, etc.

None of the standard operation numbers should be changed once they are assigned, nor should an old number on any one operation sheet be used for a new operation if the old one is discontinued. For instance, if operation number 40 were "chamfer one end," the number 40 should not be used again for another operation even if the chamfer operation is discontinued. Thus if the chamfering operation is re-instated later, the same number 40 will be available and confusion between old and new factory records may be avoided.

Some plants try to reserve the same number for each of the various operations regularly done in the plant. Thus 10 could always be a drilling operation; 20, a milling operation; and 40, a broaching operation. This system has serious deficiencies, however. What happens when a drilling operation is necessary more than once in the production cycle of any part? Operations 10 would not distinguish between the several drilling operations. If piecework were to be paid to different workmen on the several operations 10, confusion in records and payroll may occur. Also, under this system, operation numbers will not necessarily be in sequence, which may be confusing.

Occasionally it is necessary to set up temporary operations for various reasons. Where wage incentives are used, the time studies for the regular operations usually are based on standard conditions. If extra time is necessary owing to harder metals, more handling, or larger stock, special operations may be added for such emergencies. Usually, the special operations can be used only where the foreman and/or production control give written approval. When such special conditions are repeated from time to time, many plants allow the special operations to be designated by a series of known special numbers. Where numbers from 1 to 100 are used for the regular operations, the numbers from 101 to 199 are used for any special operations. Another plan uses a letter such as A or S to follow the regular operation number to designate that it is special and to be used only when approved by the proper person. Thus if the first regular operation number 10 needs the occasional use of a special material or machine, the special operation is known as 10S.

Since special operations usually involve extra cost in one form or another, their use should be carefully controlled and the extra cost charged against the proper cause of the extra work.

Setup Costs for Each Operation. Setup estimates should be made to prevent excessive costs where possible. Sometimes it is cheaper

Part Sketch

Part Name Rear Stud Part or Drwg. No. 58118

Material Data			Operation No.		No. of Sheets	
Revised			Change Date		1	
			Signed		Sheet No.	
			Material		Date	
			Pattern		Signed	
			Sizes		Designed	
			From Dept.		Routed	
			Accum. Pt.		Priced	
1	Turn, three diameters, face to length, thread and cut off	200	75	50	Standard box tools geometric die head and cut off tool	Crib A
2	Saw slot	83	25	120	1/16" screw slotting saw Fixture #F85	Crib A
3	Drill small hole	111	5	50	1/8" drill Fixture #F85	Crib B
4	Clean	20	0	500	Use specification number 458 method number 2	
5	Inspect 20 pieces at random from lot of 350	1125	Gage number G48 Gage number G51 Gage number G52	Crib D
6	Deliver to stockroom H					

FIGURE 3. Operation sheet.

MANUFACTURING LAYOUT RECORD					
IF THIS LAYOUT CANNOT BE FOLLOWED, NOTIFY LAYOUT ORG. AT ONCE.				DRWG. P-215577	
DEPT. 337	OPERATIONS <i>Rough turn, finish turn and face radius, thread, form and remove burrs, shear and cut-off See operation print</i>		TOOLS AND SPECIFICATIONS <i>Chuck C-83618 Feed Finger C-9591" 1" Feed Cam 7/16" Lead Cam - N-42280 1/4" Form Cam 3/8" Cut-off Cam Die Cam Roller Box Tool C-100044 Blade C-58008 45 Deg. Box Tool C-96220 Back Rest C-71167 6 Sets Blades C-100012 .164" - .30 Die C-4968 Die Holder C-99219 Die Adaptor C-48072 Cir. Form Tool C-100016 Shearing Tool C-100048 Shearing Tool Block C-100047 Holder C-98960 5/64" Cir. Cut-off Tool C-74805 Spec. 50069 Method #3 Female Clamping Disc C-100043 Male Disc C-92032 2-3/4" x .045" x 3/4" Saw Spec. 50069 Method #3</i>		MACHINES <i>9/16" Model "C" Acme Auto.</i>
	Clean				#1 New Type W.F. Slotter
	Slot				
	Clean				
	Inspect				
DELIVER IN CONTAINER NO. 533			UNLESS OTHERWISE SPECIFIED.		
ISSUE 9/11/38	SHEET NO. 1	NAME OF PART Fil. Hld. Mach. Screw		DRWG. P-215577	
REPL. ISSUE 8/26/37	SHEETS IN SET 2	APPARATUS			
FROM STORE	QUANTITY PER 1000 PARTS	STOCK NUMBERS	PART NO. OR DESCRIPTION OF STOCK		DELIVER TO DEPT.
203	29.93 #	559796	3/8" x 8 ft. Round Screw Machine Steel Rod Spec. 57611 103 pcs. per 8 ft. Rod 9.71 - 8 ft. Rod per M pcs.		337
ISSUED BY LAYOUT ORG.			DO NOT REMOVE THIS LAYOUT FROM BINDER		

Western Electric Co.

FIGURE 4. Operation sheet showing all tools, machines, and materials.

Tool Requirements for Each Operation. For operations requiring auxiliary tools, the operation sheet should list the tools by name for each operation. In addition, it is an advantage to list the location

of the tool crib also if the plant has more than one. Special tools are determined during the product analysis, and each one should have a unique number by which it may be identified. Such numbers appear on the operation sheets as shown in Figures 3, 4, and 5.

When the operation sheet for a certain part has been completed with all the required tools listed by name and number as shown in Figures 3 and 4, the tool crib has a record which can serve as an official list for the tools used on any operation. When the production control system notifies the tool crib to have the tools for a certain operation ready for delivery to a machine on a certain day, the tool crib attendant knows just which tools are required. Some companies have their tool departments maintain tool files which show all the pertinent data including the location of all tools in stock. If such information can be indexed satisfactorily, it becomes a valuable guide to the more complete and easier use of such tools for possible use on future orders.

Figure 4 illustrates a good method of writing an operation sheet to show machines, tools, material, and sequence of operations. This sheet shows the operations for part P-215577. (See page 151 for print of this part.) Figure 5 shows the setup and standard times in addition to the items mentioned above. It does not specify material, however. Figure 3 illustrates a more comprehensive form for recording operations which may be used in a variety of situations.

Description of Operations. In general, the operation sheets list the various operations by single words, such as blank, turn, bore, bake, filter, cut, or perforate. (See Figures 4 and 5.) Sometimes phrases are used, such as "cut to size," "finish turn and face radius," and "paint underside," to describe what needs to be done. In many situations, this kind of information is ample.

Where study of methods has been used to devise time- and labor-saving techniques, each operation may be carefully described on an instruction sheet, as shown in Figures 6 and 7.¹ In Figure 6 an operation is explained to show the sequence of seventeen elements necessary for a spur gear during one chucking. The mechanic on the job follows the sequence but does the outlined work in his own way.

The instruction sheet shown in Figure 7 is a detailed motion study written to explain the various motions to use during the operation.

¹ *Cost and Production Handbook*, L. P. Alford, Ronald Press, 1934, pp. 232 and 234.

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Not only the elemental sequence but also the motions during each element are outlined for the workman. This type of instruction sheet

INSTRUCTION SHEET						NO. _____	
PART NAME <u>Spur Gear (American La. Fr. Fire Eng. Co.)</u>						PART NO. <u>2R 302</u>	
OPERATION NAME <u>Turn O.D. Both Sides of Face & One Side of Web.</u>						OP. NO. <u>5</u>	
DEPT. <u>11</u>		MACH. CLASS <u>57</u>		MACHS. <u>Luby</u>			
MADE BY <u>W.C.</u>		APPROVED BY <u>D.V.</u>		DATE <u>8-1-</u>		MAT'L <u>SAE 5220</u>	
NO.	OPERATIONS	TOOLS - JIGS, ETC.	CUT SPEED		INCHES FEED		TIME
			R. P. M.	FT. / MIN.	PER. REV.	SETT. ING.	
TOOL LAY-OUT							
SET - UP TIME							
PROCEDURE							
1	Chuck blank, start mach, and set stop, advance and set carriage						97
2	Index and advance turret. Feed						41
3	ROUGH O.D.	A - 1/4" Sp. Stellite	23	80	.0104	96	9
4	ROUGH TWO SIDES	B - Two 3/4" Tools	28	80			80
5	Change speed and feed						08
6	ROUGH WEB	E - Form Tool Spec.	13	38	.008	128	1
7	Back index and advance turret. Change speed and feed. Throw in feed.						25
8	FINISH O.D.	C - 3/4" Tool	60	210	.0104	96	60
9	FINISH SIDES	D - Two 3/4" Tools	60	210	.0104	96	4
10	Change speed						30
11	FINISH WEB	F - Form Tool Spec.	8	24	.0104	96	06
12	Stop mach, and back turret						50
13	Back tool - post carriage and index tool - post. Advance carriage and start mach, Change speed						14
14	ROUND O.D.	G - 3/4" Flat Tool	23	80	H	and	56
15	Advance tool - post						35
16	ROUND INSIDE of RIM	G	23	67	H	and	08
17	Back carriage and remove blank						30
							72
Note - Back and index tool - post for #10 during #3 Advance carriage and set, and throw in feed for #10 during #9							
BASE TIME for 1 piece							20
Allowance 5%							1
TIME for 1 piece							21

FIGURE 6. Instruction sheet to show how operation number 5 is performed.

is economical only where the job is performed continuously or by a number of workmen at the same time. Real savings may be made by such instruction sheets if production is high and will continue so for long periods.

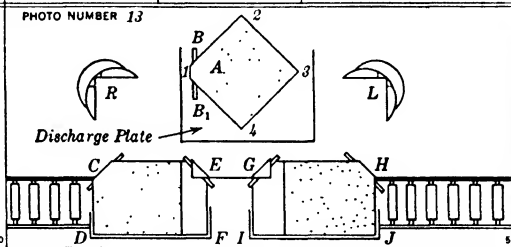
INSTRUCTION SHEET FOR OPERATION					SYMBOL No. 10		
DRAWING NO. 40	MACHINE NO. 11-12-13-14 41	ORDER NUMBER 42		NO. OF SHEETS 2 SHEET NO 1 43			
MATERIAL Slated 44	PIECES IN LOT 16" Latite 45	PIECES IN LOT 82/Sq. 46	TIME FOR LOT 47	BONUS Sheet of 12-30 48			
DESCRIPTION OF OPERATION Stacking 16" x 16" latite shingles into wrapper held in fixture of packing conveyer. Operations performed by man at position R.		PHOTO NUMBER 13 					
LINE NO.	DETAILED INSTRUCTIONS		FEED B	SPEED F	SUB OPER'N TIME PER PIECE G	TIME FOR ENTIRE LOT H	CONTINUOUS OR RUNNING TIME I
1	A-First and every odd numbered shingle						
2	in order of stacking. (See sketch above)						
3							
4	Press down at point "A" of shingle						
5	on discharge table with the left hand, palm						
6	downward, and slide it toward the wrapper,						
7	in the meantime allow it to turn slightly						
8	in a counter-clockwise direction						
9	about its center.						
10							
11	Release pressure with the left hand						
12	and grasp the shingle at "B" with						
13	the right hand, palm upward, fingers						
14	underneath and thumb on top. Move						
15	left hand towards the next shingle on						
16	discharge plate.						
17							
18	Move shingle into wrapper with the						
19	right hand, swinging it counter-						
20	clockwise so that the slated side will						
21	be underneath.						
22							
23	Release the shingle in the wrapper						
24	when the corner "1" is at "E" and						
25	the corner "4" is at "F".						
26							
27	B-Second and every even numbered						
28	shingle in the order of stacking.						
29							
30	Press down on center of shingle						
31	with left hand, palm downward. Slide						
32	it towards the wrapper until corner "1"						
33	extends over the edge of the discharge						
34	plate.						
35							
36	Grasp the ear of the shingle with						
37	the right hand, palm upward, fingers						
Effective			MONTH	DAY	YEAR	APPROVED	
JHW			7	9		JAP	
						BY SFC	
						8/26/-	

FIGURE 7. Detailed instruction sheet for the operation of packing shingles.

[illegible]

FIGURE 8. Combination operation sheet and form to release manufacturing orders.

Operation Sheet										SHEET <u>1</u> OF <u>1</u>	
MFG. ORDER NO. 5806		PART NO. 7182-1		PART OR ASSEMBLY NAME Suction Tank Mounting Bracket		ECON. LOT SIZE 300		% MATERIAL OVERAGE 5		PART NO. 7182-1	
QUANTITY IN ORDER 300		QUANTITY OF MATERIAL WANTED Use Clippings		MATERIAL NAME 50227-C.R.S. Sheet		APPROVED TOOL DESIGN L.C.		DATE 11/20/46		PROD. SUPT. G.T.M.	
DAY RELEASED 1/3		DATE DUE 1/28		SCHED. BY J.B.		SIZE AND SPECIFICATION 1 3/4" x 3 7/8"		QUANTITY OF MATERIAL REQUIRED PER 100 700 sq. in.		OPER. NAME	
START. DATE		HOURS SCHOL.		STD. HRS. PER 100		SET UP TIME		P.C.		EQUIPMENT NAME	
1/17	1.6	0.5	0.1	640	Niagara abear	10	Cut to size				
1/17	1.3	0.4	0.1	650	Niagara abear	20	Clip corners				
1/20	0.7	0.2	0.1	650	Portable grinder	25	Burr				
1/21	2.1	0.6	0.3	652	Sturdy bender	30	Form		"V" die		
1/24	2.6	0.8	0.2	670	Drill press	40	Drill two (2) holes		# 25 drill, drill jig # 90214		
1/27	2.8	0.9	0.1	670	Drill press	50	Tap two (2) holes		10/24 tap, plug gage #91528		
1/27	0.7	0.2	0.1	670	Portable grinder	60	Burr				
1/27	0.75	0.25	-	500		70	Final inspection		Plug gage #91529		
1/28							Move to 370 stores				

Figure 9. Operation sheet combined with manufacturing order.

220 ROUTING, OPERATION SHEETS, AND INSTRUCTION CARDS

A large number of plants have arranged space on their regular operation sheets to include variable information needed to release a manufacturing order for the part or material. Such combinations of information reduce the number of forms required to provide adequate information to the shop where parts are made in lots period-

SHOP ORDER

PAGE 1 OF 1

PART NO 02943-N		ORDER NO 4725		FOR COMPOSITE NO 859-NA		DESCRIPTION Safety Collar				PART NO 02943-N	
DEL TO HPWS 1000		PCS REQ'D 3900		SCHEDULE 4/28/48		ROUGH SIZE 7/8" dia. x 1-5/16" long		FINISHED SIZE 1-1/8"		DRAWING NO	
DATE ISSUED 3/21/48		PAGE 1		M O NO & MACH. 5 C#1620		MATERIAL SPEC CRS 1015-20		CUT FROM 12'-7"		RGH WT. FIN WT. 223	
DEPT. NO.		MACH. NO.		OPER NO		DESCRIPTION OF OPERATION		TOOLS & EQUIP.		RATE PER 100 SET UP RATE HOURLY PROD QUAN & DATE CPLY	
17		A-13				Rough stock					
35		6205		5		Drill, groove, chamfer & cut off				.45 2 .25	
TW2				10		Cyanide harden & ctr. less grind					
29						Disposition 864-NA (1)NCM baler					
85						Disposition 859-NA (2)NCM baler					

MIN. ECON RUN		ECONOMICAL RUN		MACH LOAD		DRAW. SIZE		TYPED BY SIS		DATE 1/30/48		CHECKED BY		DATE 1/30/48		DATE REVISED	
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FIGURE 10. Operation sheet for incentive wages combined with manufacturing order.

ically. Figures 8, 9, and 10 are examples of the tendency to include all pertinent information for a certain manufacturing order on one sheet. The upper left-hand corner, enclosed by the heavy line in Figure 8, contains both variable and constant information needed by the dispatchers, foremen, and workmen to know what is wanted. The manufacturing order number is a unique number applied to each release for control and accounting purposes. The part number is repeated here because the left-hand corner only is reproduced for the material requisition form. (See Chapter XXIII.) The "quantity in order" is the number of units actually to be made on the manufacturing

order number. The "quantity of material units" is the amount of material requisitioned from stores to complete the order. This quantity is greater than the quantity in order by the percentage shown in material overage. This percentage is obtained from the average percentage of scrap made during past orders of the same part. The "material wanted" column gives the date scheduled for beginning the first operation. The "day released" is the date the manufacturing order is ready to be duplicated and sent to the dispatcher. The "date due" is the date when all work is supposed to be completed on the order and parts delivered to the stockroom or assembly floor. The "date of latest print" is important for the dispatcher and mechanic. The mechanic can check his print to be sure that he has the latest one. Work may often be spoiled if one is not sure whether the print or specification is up to date. The economic lot size tends to be semi-constant as it varies only when the rate of use of the part, the setup time, or other factors change in the determination of the economic lot size. (See Chapter XX.)

The "material name," "material specification and size," and other material information is taken directly from the engineering data for the part. This material information in conjunction with the quantity of material units constitutes the material requisition information discussed in Chapter XXIII.

The upper right-hand corner is reserved for effective and changed dates with reason for the change. To insure a unanimity of opinion on the manufacturing of the part the three persons often involved sign the sheet to make it official.

The long vertical columns in Figure 8 are mostly self-explanatory with the following exceptions. The "hours load this order" when used with setup time plus standard hours or estimated hours on each operation will give the total hours load for the various operations. The process center is designated by a number to show departments or sections of departments depending on the accounting procedure. The machine group refers to a group of similar machines upon which the part or material can be made. However, the standard hours are set on the best machine of the group. The machine used is usually one of the specified group but it tends to show why the actual hours taken for the operation may vary from the standard hours or the estimated hours.

The operation sheet shown in Figure 9 is a variation of Figure 8. The principal differences are the starting date column entered by the dispatcher to show when he should start each operation in order to get the part done by the date due, and the dispatched and date

[illegible]

FIGURE 11. Dispatcher's copy of a manufacturing order.

columns giving the date when the operation actually started and the initials of the dispatcher.

Neither Figure 8 nor Figure 9 is used in shops with a wage incentive. All jobs are done on day work where variations from standard time are recorded to process center accounts for the foreman's action.

Figure 10 illustrates a similar operation sheet with a rate per 100 of 45 cents and a setup rate of \$2.25 for a piecework shop.

Figure 11 is similar to Figure 8 but it has some different features and is only 5 x 8 inches which makes it more convenient to handle and file.

Specifying Grade of Labor. Some plants specify the grade of labor to be used on each operation. This may be expressed by stating the pay per hour or by a labor symbol which designates a skill or wage group. The Western Electric Company uses a series of numerical symbols² ranging from 1 to 20 for men's occupations and from 51 to 56 for women's. The thousands of different operations in the plant are studied by a job-analysis technique and fitted into a table to show the proper grade number for each job.

Each of the grade symbols includes the degree of skill and a range of hourly rates along with other scientific job requirements.³ Consideration is given to strength, training, experience, alertness, nimbleness, accuracy, and responsibility required of the operator, and safety, job hazards, strain, monotony, and other job characteristics which may be potent factors in assigning the labor symbol.

This scheme may seem rather elaborate to some plants, but where a large variety of different kinds of work is done in different departments it is necessary to keep equitable rates throughout the plant. For instance, grade six drilling operations were performed in eleven different departments under as many foremen. If each department had set the rate for the similar jobs the results probably would not have been uniform.

If the type of labor is specified either directly or by some symbol, the specification usually carries a range of hourly wages paid for each grade. The specification insures that the proper type of person for the job will be hired by the employment office. On the other hand, if *only* a range of hourly or piecework wages is given for each operation, the proper grade of personnel may not be selected so accurately.

² *The Place of "Planning" in Production Control*, G. A. Landry, Published by Western Electric for S.P.E.E. School for Mechanical Engineers.

³ *A Job Analysis of Manufacturing Plants in Minnesota*, Charles A. Koepke, University of Minnesota Press, 1934.

Placing the wage-payment method directly on the operation sheet does help the foreman, however, to exercise his judgment in the selection of the proper person for a particular job because of the job's earning capacity. The operation sheet sometimes prescribes the wage-payment plan used for each operation. Whether the workman uses clock hours, standard hours, pieces, or points, depends on the wage-payment plan; the operation sheet usually states which one to use.

TABLE 1
CLASSIFICATION OF JOBS BY DEPARTMENTS

A. Molding Department	C. Cleaning and Shipping Department
1. Floor molder	22. Tumbler men
2. Machine molder	23. Chippers and grinders
3. Machine molder finisher	24. Sandblast room operator
4. Bench molder—loose patterns	25. Sandblast helper
5. Squeezer molder	26. Finisher—first class
6. Molder's helpers	27. Finisher—bench—cylinders
7. Flask carrier	28. Inspectors
8. Facing mixer	29. Welder
9. Shakeout and general labor	30. Truck driver
10. Flask carpenter	
B. Core Department	D. Melting Department
11. Jacket makers	31. Cupola tender
12. Floor core makers	32. Cupola chargers
13. Machine core makers	33. Cupola laborer
14. Core blower	34. Ladle liner
15. Assembler	35. Yard laborer
a. Expert	36. Laboratory assistant
b. Good—all dry sand jobs	
16. Core sand mixer	E. Miscellaneous
17. Sand delivery man	37. Pouring gang
18. Wire cutter	38. Maintenance men
19. Core piler	39. Patternmaker
20. Core carrier	40. Sweeper
21. Electric truck driver	41. Car unloaders

Example of Job Standardization. E. L. Roth ⁴ describes a job standardization program in use in a Milwaukee foundry. His first step is to list each job in the plant by departments. For example, the classifications used are shown in Table 1. Since there are probably no two jobbing foundries making exactly the same kind of castings, there would be many variations and the detailed description of the work to be done on each job classification would differ widely.

⁴ "Practical Job Evaluation for the Small Foundry," E. L. Roth, *Transactions of the American Foundrymen's Association*, Vol. 47, p. 925.

TABLE 2
FACTORS IN EVALUATION OF JOBS

Factors	Per Cent
1. Time required to learn trade.....	23
2. Time to adapt to conditions.....	7
3. Scarcity of labor.....	5
4. Difficulty in getting another job.....	4
5. Educational requirements.....	8
6. Prevailing rate of pay.....	5
7. Accuracy and skill required.....	9
8. Ingenuity.....	7
9. Manufacturing hazard.....	6
10. Honesty of effort.....	7
11. Dirtiness of working conditions.....	3
12. Health hazard.....	7
13. Accident hazard.....	3
14. Physical effort.....	3
15. Monotony.....	3
	<hr/> 100

TABLE 3

BREAKDOWN OF FACTORS ONE AND SEVEN IN TABLE 2

Factor 1—Time required to learn the trade

Multiply by 23 (from percentage shown in Table 2)

Years of Experience	Points to be Allowed
9 to 10 (or more)	10
8 to 9	9
7 to 8	8
6 to 7	7
5 to 6	6
4 to 5	5
3 to 4	4
2 to 3	3
1 to 2	2
Less than 1	1

Factor 7—Accuracy and skill required

Multiply by 9

Degree	Points to be Allowed
Very skillful (toolmaker)	10
Skillful (machine operator and patternmaker)	8
Ordinary accuracy and skill	5
Little accuracy and skill (bench assembler)	3
Practically no skill (laborers)	1

JOB ANALYSIS SHEET

Description of Work: *Patternmaker, Customer Pattern
Changes, Mount Patterns Add Gates,
Repair and Maintain Prod. Patt's.*

Factor No.	Weight Multiplier	No. Points
1	23×10	230
2	7×5	35
3	5×6	30
4	4×1	4
5	8×10	80
6	5×8	40
7	9×8	72
8	7×10	70
9	6×8	48
10	7×6	42
11	3×2	6
12	7×1	7
13	3×4	12
14	3×1	3
15	3×1	3

Total 682 points

FIGURE 12. A sample mimeographed form for tabulating factors of a job analysis.

The job evaluation or standardization is usually determined by a group consisting of the foreman, key workmen, shop superintendent, and personnel officer if the shop has one.

The job standards for each classification shown in Table 1 are made by using the fifteen factors illustrated in Table 2. Table 3 shows a breakdown of several factors to illustrate the method used. Only factor numbers 1 and 7 are shown here. (For more complete information on these factors see the original article.)

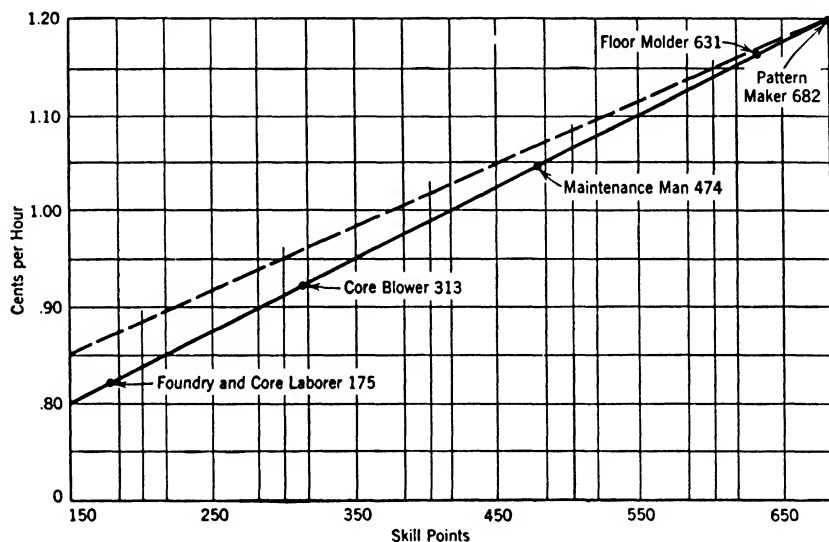


FIGURE 13. Chart for setting day work rates according to skill points.

A convenient form for tabulating the results obtained from the breakdown of the factors in Table 2 is shown in Figure 12. This tabulation is used to set up the standards required for the pattern-makers in this Milwaukee foundry. Because of the wide variation of conditions in different shops each plant should make its own job standards study.

After the standards have been set up for each type of job, the one with the lowest number of points is paid the chosen minimum (here, 80 cents per hour); the job with the highest number of points is paid the chosen maximum (\$1.20 per hour).

The heavy solid line in Figure 13 shows the wage differential for the various jobs when the limits are placed from 80 cents to \$1.20 per hour. The dashed line shows how the wage rates would differ if the minimum were increased to 85 cents per hour.

Care of Operation Sheets. Operation sheets should never be duplicated or altered by anyone except the industrial engineering or production control departments. Unless such authority is centralized, chaos and trouble will result. Each department which performs an operation on any part should have a copy of the operation sheet in its file; in some plants, only the current jobs in a department have operation sheets furnished with each manufacturing order when it is released. If any change is made by the control office, the corrected copy should be placed in the file by a representative of the control office. At the same time the old sheet should be destroyed by the same representative. All operation sheets in each department should be filed in the numerical order of the part numbers. In some plants where numerous individual parts can cause confusion, the design or control office furnishes each department with a cross index of part names and part numbers. If a person knows either one, he can find the other by cross index.

The control office should keep all the operation sheets that have been written for each part number. The sheets should be chronologically arranged for each part number and kept in books filed by part numbers. Thus the history of all changes is on file to prevent changing back and forth between two alternative methods. The history file can prevent reversions to methods which have been tried before and have been found faulty.

Suggestions for changes in the operation sheet may originate from the control office or from the foreman. The request for changes should be written out on a special form (see Figure 2 or Figure 3, Chapter V) so that they may be checked for validity and economic soundness. Foremen sometimes ask for temporary changes but these usually can be handled by special operations which are marked temporary or given special numbers designating special operations. Changes in operation sheets, however, which are due to mistakes in the initial planning procedure may prove very costly and should be avoided by employing men who are both accurate and careful.

Effect of Engineering Changes on Operation Changes. When the engineering design office changes the blueprint of a part, an operation change is often required. Such changes are sometimes expensive because new tools may have to be made or old ones altered. Excessive stocks of material may become obsolete if design changes are made effective before the old stock is used. The sequence of operations is frequently altered by design changes. This involves a rewriting of

the operation sheet and a different routine in the shop which may cause some dissension for a time due to workmen and foremen preferring old habits of production. Design changes are necessary from time to time to improve the performance of the product, to lower cost of production, or to take advantage of improvements in the art of manufacturing, but they should be timed properly and studied carefully for economic loss or gain before they are made.

Effect of Incentive Wage Changes on Operation Sheets. When the wage-payment plan involves piecework rates expressed in dollars for a certain number of units, the operation sheets must be changed whenever the basic wage rates rise or fall. This may mean a complete review of all the piece rates on each operation sheet if the rates are kept up to date. Some companies attempt to avoid such wholesale changes by mentally adding or subtracting something from the old operation sheet rate each time a job is run. But after several such changes, considerable confusion may exist in the plant about the correct piecework price. The standard time per piece or any of the point systems used to designate a period of time for an operation rather than a sum of money are much more stable than dollars for a certain number of units. Under standard conditions the time per unit is quite constant. The workers on incentive collect points or standard hours whose worth may vary as the basic wages go up or down. When this latter plan is used it is seldom necessary to change the operation sheets unless the methods change.

Accumulation for Assembly. Synthetic industries which make their products by assembling a number of parts always have the problem of accumulating the parts at the proper locations. All material ready for a sub- or final assembly is usually finished stock. It should be routed, after the final operation on each part, either to a stockroom or to an assembly work station. The last notation on the operation sheet for each part should state where the part is to be accumulated. If the accumulation point happens to be a stockroom, the stockkeeper should not be asked to deliver any material to the assembly floor until all the necessary parts have arrived in the stockroom.

Master Parts List as an Aid to Accumulation. There are several ways to accumulate finished parts for assembly. A master parts list may be used to show how parts are combined to make up the various sub-assemblies and how the several subassemblies are combined to make up the final assembly. Figure 7 of Chapter V shows a simple graphic approach to the problem by listing the part numbers only, grouped

to show those entering into the first subassembly. The first subassemblies are in turn grouped to show those entering into the second subassembly, and so on, until the single parts and subassemblies entering into the final assembly are shown in the column headed numbers in final assembly. This type of parts list is often used in production control offices because it is compact and complete.

Figure 9 of Chapter V shows how the same information plus part names can be placed in graphic form in the nature of a flow chart. If desirable, accumulation points could be identified on this chart to show where the various sub- and final assemblies are made. Moreover, a graphic chart, such as this, often can be helpful in setting up the master time schedule. (See Chapter XXI.) Though this information should be on the individual operation sheet for each part, it is difficult to visualize the interrelationships by using the information as written on the many operation sheets for a complicated product.

Either of the two methods illustrated in Figures 7 and 9 of Chapter V may be used to accumulate stock at certain assembly stations if the assembly is continuous. Either method may be used in certain stockrooms if assembly work is done spasmodically on only one or several units.

Accumulation in Mass-Production Plants. Accumulation of parts for assembly work is done more or less automatically in some mass-production plants. The parts finished in the plant are placed on conveyers which deliver the parts to assembly points as fast as they are needed. The subassemblies, in turn, are placed on other conveyers to be delivered to the next assembly, and so on, until all parts and subassemblies are brought to the final assembly line at the proper time to produce the product. Single parts such as bolts and washers, which are usually purchased finished, are often placed in boxes or bins at the point of use. The workman helps himself as the parts are used!

The operation sheet, instruction card, parts list (preferably graphic) and blueprints enable the shop to have the right information to make any product whether it be simple or complicated. The superintendent, foremen, and workmen no longer find it necessary to remember a mass of detail which may be remembered differently by different departments. The large number of parts and materials now used by the average plant makes it necessary to have all data and procedures in written form so that all departments may proceed more easily on production matters.

QUESTIONS AND PROBLEMS

1. What are the important differences in the operation of a factory with operation sheets and without them?
2. How much authority should the product analysis and tool design groups have over the design of a part?

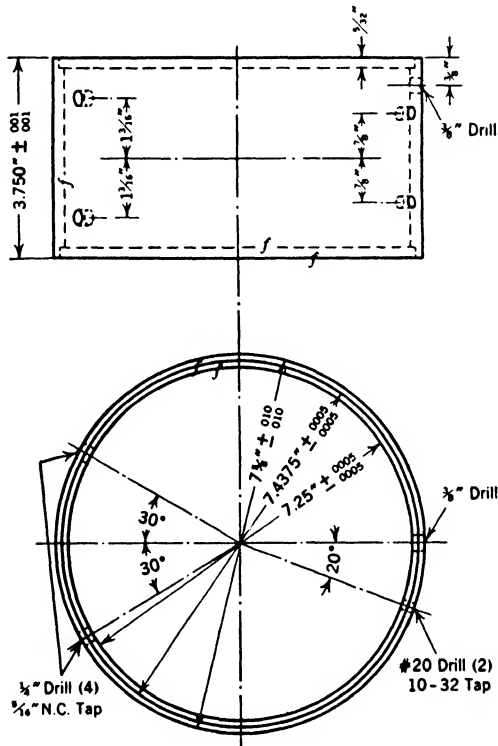


FIGURE 14. $\frac{1}{2}$ -horsepower induction motor stator frame.

3. What effect does the quantity produced have on operational procedure?
4. Specify the material completely for the stator frame shown in Figure 14. Prepare the data for an operation sheet. Consider tubing or rolled sheet and welded construction.
5. What effect does method have on routing?
6. From your knowledge of brickmaking how would you route the material through the plant? Write an operation sheet to show the operations. When would the routing need to be changed?
7. A woodmill gets an order for a special size, four-pane, gliding window frame. How would you route it through the shop?

8. Write a complete operation sheet to produce 10 (only) bearing brackets as shown in Figure 15.

9. Write an instruction sheet for the elemental operations for the work done in the first chucking on the bearing bracket shown in Figure 15.

10. Make up a master parts list to show the parts, subassembly, and final assembly of your favorite clutch pencil.

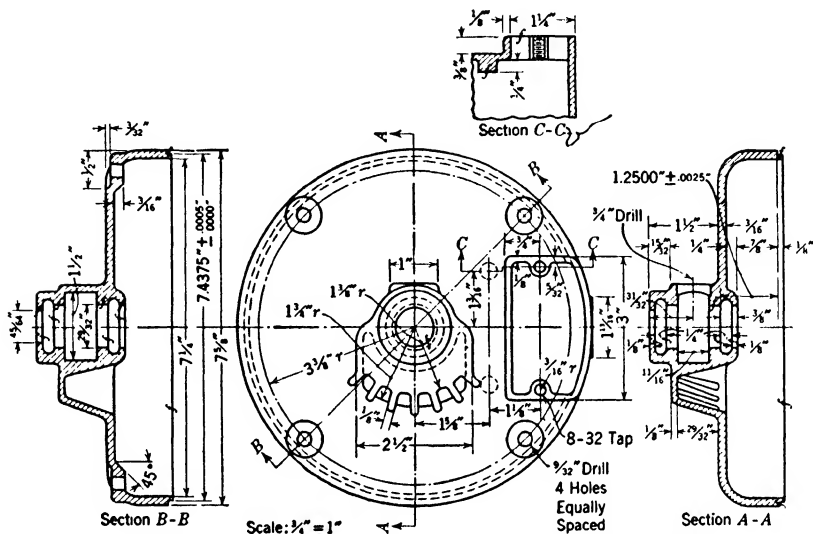


FIGURE 15. $\frac{1}{2}$ -horsepower induction motor bearing bracket.

11. Describe the accumulation system used in a plant you have visited.

12. Make a graphic master parts list chart for any product with at least twenty parts.

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CHAPTER XII

ESTIMATING PRODUCTION AND COSTS

The work involved in preparing estimates for the manufacture of a new product is an essential function of production control. When a new product has been developed or an old one has been improved enough to warrant possible commercialization, the production control department is usually asked to estimate the cost to manufacture the product. Job shops usually work from the drawings and specifications of their customers. Before bids can be submitted for new work it is necessary to estimate the labor, material, and overhead for each part. These estimates are used for different purposes and the degree of accuracy required depends on the purpose of the estimate.

APPROXIMATE ESTIMATES

Sometimes a rough estimate of the probable cost is sufficient. An inventor may bring simple sketches or just an idea to a job shop to find approximately how much a model would cost. He may naively expect the work to cost only a few dollars. A rough estimation may place the cost much higher than the inventor anticipated. He then must determine whether the project warrants the additional expense of detailed accurate drawings which would make an accurate estimate possible.

Each type of industry has its own way of arriving at approximate estimates. Certain machines are roughly estimated at some price per pound. Within certain classes of machinery such as engine lathes for instance, the selling prices may vary from about 42 cents per pound for ordinary mass-produced cheap lathes to over \$1 per pound for the fine tool room lathes. New machines in these groups could be estimated roughly by first placing them in a known group and then applying the known manufacturing cost per pound to the estimated weight.

The building industry uses a known cost per cubic foot for buildings which are similar to the proposed building. Adjustments may need to be made in the estimated cost of the proposed building for current costs of labor, material, and overhead as compared to these

costs on the old building. The type of building has a considerable effect on the cost per cubic foot. Simple frame structures with no heat or toilet facilities and with plain cement or cinder floor may run as low as 8 cents per cubic foot. Well-built multi-story factory buildings with elevators, heat, and plumbing facilities cost 40 cents or more per cubic foot.

A rough estimate usually can be only an expert guess. When men have estimated *similar* jobs for many years, they become quite proficient at arriving near the actual cost. However, as margins of profit tend to become smaller in modern business, it is necessary to avoid the use of short cuts leading to approximate estimates for bidding purposes. Quite often new products may look similar at first glance, but only close study of all the drawings and specifications can assure the inclusion of all costs that the obscure changes may involve. Poor cost estimating for bidding purposes can be a double-edged sword cutting profits from two directions. If bids are too low profits are reduced or absent, and if bids are too high the company cannot get the business.

ACCURATE ESTIMATES

The request for an accurate estimate must be accompanied by complete drawings, models, or specifications of the proposed product. Sometimes all three are desirable or even necessary to convey properly all the ideas to the production department. In addition, it is necessary to have information concerning materials, specifications, tolerances, and other aspects of inspection, and the quantities to be manufactured for each part.

Cost Estimates as a Basis for Price. Some products, such as large turbines, large special machinery, the ornamental iron work for a public building, or those things which are not manufactured for mass consumption, require cost estimates as a basis for bids. Usually prices cannot be quoted to prospective customers unless the manufacturer knows the actual or estimated costs to produce the goods. Where monopolies, manufacturing or design superiority, or certain patents give advantages over other manufacturers, it is generally possible to use cost as a basis of price, but, if any plant allows these costs to rise too high, competition will find a way to underbid, and the ideal of using cost as a basis for price setting is lost.

Overhead Cost as an Element in Price. If a plant has facilities for handling a large volume of products but at times does not have sufficient volume to pay all the overhead cost, it may be good policy to bid on new business at little or no profit. This low-profit business

could pay some of the fixed burden which might not otherwise be recovered. In times of low business activity this is often done to reduce a large loss in overhead recovery. This system is an evil of overcapacity, and if it is generally practiced by many plants in an industry we have the profitless prosperity which was often mentioned during the 1920's. It is impossible to make formulas or rules for determining selling prices because the vicissitudes of business require constant attention and good judgment in order to preserve balance between the buying and selling markets. When goods are sold in strong competitive markets, present costs sometimes must be neglected in fixing sales prices, and profits, if any, must come by a reduction in the costs of manufacturing.

Manufacturing costs are often driven downward by the sort of "squeeze play" discussed above. When pressure is applied to reduce costs so that a profit may be made at present sales prices, improved methods are often developed to achieve the necessary reduction. In modern production shops it is becoming increasingly difficult to make large single reductions in unit cost unless the process, the material, or the design is changed. The use of die castings, for instance, as compared to sand castings can make large savings in unit costs provided the quantity desired is sufficient to warrant the die castings. (See Chapter VI.)

More often, however, cost reduction is accomplished by the aggregate of small savings from a large number of operations. The concerted effort of all factory employees coordinated by a good methods department can constantly whittle away at excessive costs. The cost estimator should know what has been done recently in cost reduction, and he should also have knowledge of future plans for reducing factory costs.

Although production control departments seldom set the final sales price, it still is important that estimated costs of manufacturing for calculating selling prices be as accurate as possible. After the usual additional overhead percentages are added to such estimated manufacturing costs, it will become apparent whether the proposed product is practicable from an economic standpoint. If the first cost appears to be too high, the design and methods of manufacturing may be re-examined to determine where costs can be pruned to bring the manufacturing costs down to a point where the product can be sold in a competitive market.

Basis for Analysis of Cost. The product analysis group specifies the operations for each part, the machines on which they will be run, and

the estimated output per hour. From these the cost can be estimated by applying the proper wage and overhead rates.

It is commonly known that the selling price is based on the costs of labor, material, and the several burden or overhead charges incurred by management and selling along with some measure of profit added. Assuming these same elements of cost are used by all vendors or shops, the wide variation in the bids for the same product is often quite astounding.

These variations may be due to a number of causes. Materials may be cheaper in some sections of the country. Some shops may have better methods of reducing waste in the use of the materials. When two competing shops are in the same district, the basic costs for material would not vary except for the quantity purchased, but if one company was already using quantities of a material which also was to be used on a projected job, they may be able to underbid their competitors because of the advantage offered by quantity buying.

Estimating Material Costs. Material costs are estimated by the gross length, area, or weight of material used per unit of product. This may be determined from previous estimates which have been made for the same or very similar products. However, since estimates may differ slightly either way from actual production figures it is better to consult the records for the amount of material used in the past for similar jobs run in the plant.

Reliability of Material Records. Though estimates or past records of materials used per unit of product are considerably better than plain guesses, both may be wrong. Estimates are never any better than the method used to gather the facts, and records may simply be recording mistakes which have occurred repeatedly in past performances.

ANALYTICAL METHOD OF ESTIMATING MATERIAL

If time or the quantity to be produced warrants the use of the analytical study method, the results are much closer to actual theoretical requirements than either of the first two methods. In this method the weight of a casting is determined by measuring the volume from the drawing, or by weighing the pattern and applying the proper factor, depending on pattern material, to get the rough weight of the casting. The shape and number of gates, sprues, and risers must be decided upon during the planning operations. The volume can easily be calculated to be added to the casting weight which gives the net amount of metal in good molds. To this must be added the average

factor for scrap castings and cupola loss (say 8 per cent) to get the total metal to be placed in the cupola for melting. If the total melt is known, then the fuel-iron ratio and flux per ton of metal can be used to calculate the amount of fuel and flux needed for each ton of castings produced.

Screw machine material is generally quite easy to estimate because lengths of pieces are fairly exact and cut-off tools have been stand-

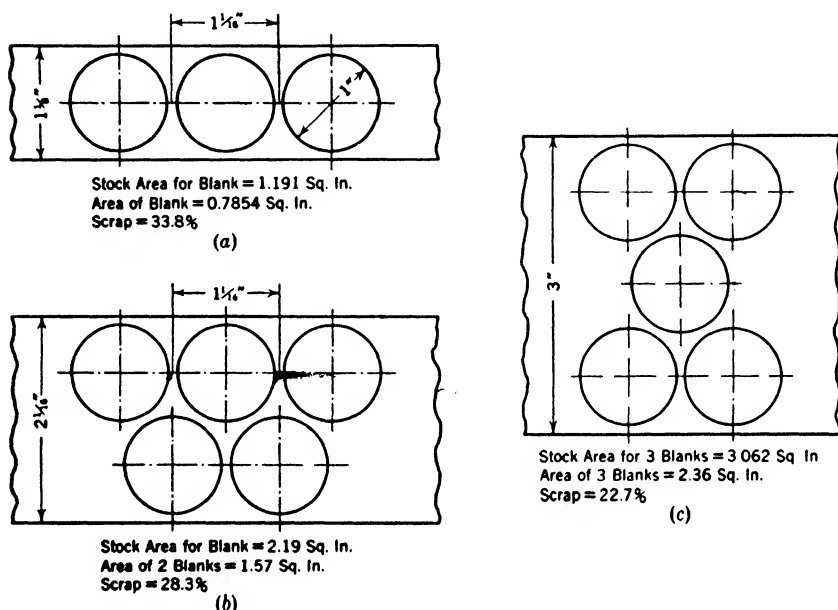


FIGURE 1. Several methods of producing disks with different percentages of waste.

ardized¹ in most shops to certain widths depending on material to be cut and the diameter of the bar.

Effects of Waste and Scrap on Material Required. Material for upholstering fabrics can run from a few cents a yard up to \$10 or more per yard. If it is cut by laying a pattern on a single thickness, the loss from poor pattern placing is not so serious as if the cloth is piled inches high and many pieces are cut at once with a power device. Careful fitting of all the needed patterns in as small a surface as possible will repay manyfold in fabric saved. Seldom can any workmen place patterns without excessive waste the first time they are used. It takes intensive application and sometimes suggested changes in design to reduce waste to a minimum.

¹ For table of widths of cut-off tools see Alford's *Cost and Production Handbook*, Ronald Press, 1934, p. 420.

When estimating material for stamping or drop forging there is always scrap produced. That is, drop forgings must be made with an excess of metal which extrudes around the edge of the die and is trimmed off as "flash." Stampings cannot be blanked from strip stock without leaving some stock to be sheared off all around the die. This margin of stock left around the punch will vary with its thickness, the size of the blank to be produced, and the design of the die.

If the allowances for the margin are not large enough, more care is required in placing the blank in the die; the die may be ruined, and excessive labor costs will consume the savings made by the smaller margins of scrap. A safe rule for estimates is to calculate margins equal to the thickness of the stock with no margins less than $\frac{1}{32}$ inch wide.

The material wasted in producing stamped articles is usually an important percentage of the original stock. Both the location of the blank in relation to the edge of the stock and the number of blanks across the width of the stock affect the percentage of scrap produced.

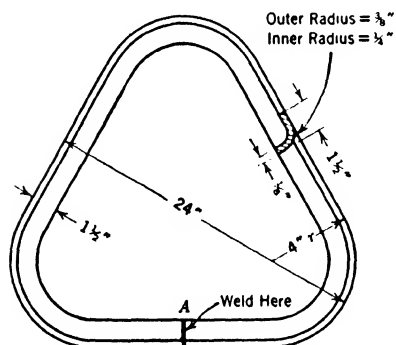
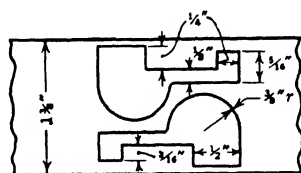


FIGURE 3. Rolled section; bent and welded, wasted no material.

A plain circular blank an inch in diameter produces about 34 per cent scrap when it is made from a strip $1\frac{1}{8}$ inches wide. Either by turning the strip over and running it through the die a second time or by making a double die (if production warrants) the scrap is reduced to about 28 per cent. A further reduction in scrap is realized if a triple row of blanks is stamped as shown in Figure 1(c).

Irregular blanks should be carefully studied to place them in the



Area of Blank = 0.578 Sq. In.
Area of 2 Blanks = 1.155 Sq. In.
Area of Stock for 2 Blanks = 2.147 Sq. In.
Scrap = 2.147 - 1.155 = 0.992 = 46.2 %

FIGURE 2. Stock may be saved by reversing blanks.

Design Change May Reduce Material Required. Design may affect estimate of material and the planner should always be looking for improvements in the use of material. The designer of the part shown

in Figure 3 asked that it be blanked and formed from a sheet. The center hole was waste material no other part could use. The estimator became alarmed at the material cost for this part and suggested it be made from a rolled steel section, bent to shape, and welded at A. No material was lost, the cost of expensive blanking and drawing dies was saved, and the part looked the same and was just as strong.

Effect of Pattern and Grain on Material Requirements. Material estimators often must consider getting the pieces out of the raw material in a certain way. The grain of woods places definite limitations on the way certain pieces can be cut from the board. Steel strip likewise has a grain although not so pronounced. There are slight scratches in the metal parallel to the direction of rolling which may cause trouble if bends are made parallel to these slight scratches. The scratch starts as an incipient crack which may cause failure if the bend is ninety or more degrees. Bends across the grain are usually necessary if the angle is greater than forty-five degrees.

Patterns in textiles sometimes have to be matched, and the larger the figure the more need for matching and the greater chance for waste in cutting. Moreover, when textile pattern figures have to be matched, the fabric usually has to be cut in single layers. Thus both labor for cutting and material costs are increased.

Certain things such as wire, metal strip stock, shim stock, and paper stock can be purchased in either sheets, rods, strips, coils, or rolls as the material comes. Each form has advantages, but some of them have the added advantage of being cheaper per pound in coils or rolls. It is the responsibility of the production control department to advocate the use of the most economical form of the material specified. The estimator should investigate the possibility of using the cheapest form in which the material may be purchased.

Accurate Material Estimates Are Necessary. Inexact material estimating can be a real source of loss. If too much material is included in the estimate, there may be a loss through leftovers which often become shopworn, or the excess material may become scrap through neglect. Material costs are becoming an ever-increasing percentage of the prime cost because labor-saving machines tend to reduce labor costs. As this proportion of material cost goes higher, the saving of any appreciable per cent becomes more important in estimating the prime cost of any product.

Careful analytical studies for estimating quantities of material are much better than other methods of estimating, but they are also more expensive. Some jobs may not be extensive enough to warrant so much time and effort to estimate the material. Each industry must

collect its own cost data and work out its own methods and allowances for estimating its jobs.

Form for Recording Material Estimate. Since materials are such an important part of most factory's prime cost, it is customary to include

DETAILED ESTIMATE FOR MATERIAL COST			
			Estimate no. <u>51</u>
Customer or dept. <u>King Conveyor Company</u>		Date <u>6-9-41</u>	
Part name <u>Conveyor Slat</u>		Part no. <u>101</u>	
Pieces needed for this order <u>600</u>		Drwg. no. _____	
Final product name <u>Bacon Conveyor</u>		Final product no. _____	
Kind of material # 1 <u>11 Gage x 6" H.R. Steel Strip</u>		Inventory price _____ per _____	
		Market price <u>\$3.85</u> per <u>100</u>	
		Future contract price _____ per _____	
Kind of material # 2 _____		Inventory price _____ per _____	
		Market price _____ per _____	
		Future contract price _____ per _____	
Kind of material # 3 _____		Inventory price _____ per _____	
		Market price _____ per _____	
		Future contract price _____ per _____	
(# 2 and # 3 are used if more than one material is used for the part.)			
<p>Quantity of # 1 material actually in 1,000 units <u>1,500</u> lb. at <u>0.0385</u> per lb. = <u>\$57.75</u></p> <p>Normal waste <u>600</u> pounds + normal scrap <u>15</u> lb. = <u>615</u> lb. at <u>0.0385</u> per lb. = <u>\$23.68</u></p> <p>Quantity of # 2 material actually in 1,000 units _____ lb. at _____ per lb. = _____</p> <p>Normal waste _____ pounds normal scrap _____ lb. = _____ lb. at _____ per lb. = _____</p> <p>Quantity of # 3 material actually in 1,000 units _____ lb. at _____ per lb. = _____</p> <p>Normal waste _____ pounds normal scrap _____ lb. = _____ lb. at _____ per lb. = _____</p> <p style="text-align: right; margin-right: 50px;">Actual cost of material used per 100 parts = <u>\$81.43</u></p> <p>Material cost for <u>600</u> parts = <u>0.6 x \$81.43 = \$48.86</u></p>			
Remarks _____		Estimated by <u>H.C.G.</u>	
(See over for diagram of method used to lay out material)			

FIGURE 4. Suggested form for material cost estimate.

in the cost estimate either a separate form or a place on a prime cost form for the material cost. Figure 4 shows a suggested form with the necessary information arranged in a logical fashion.

Scrap and spoilage allowances are based on the plant's experience with similar work. If the part is stamped from a strip or cut from a sheet of material, a diagram should show the method the estimator used to lay out the pieces from the raw material. If the workman or

foreman is not told how to get the maximum use of the material as the estimator planned, the final material cost may be higher than planned. Estimated waste and scrap should be recorded to show that it was considered, and in what amount, in the final material cost.

The estimator's diagram for showing how the material is to be laid out can be drawn on the reverse side of the material cost estimation sheet, Figure 4.

The cost of any material per pound usually varies from one period to another. Moreover, at any given time material can be priced from three different viewpoints. Material from inventory is priced at some past value which is on record; material to be purchased and used immediately is priced at the present market value; but if material for orders which are to be manufactured later has to be purchased in the future, then future prices secured by a contract will provide the safe price to use for estimating material cost (see Figure 4).

This form for estimating material costs is one to be used for general-purpose work. It is designed to show the cost for one to three materials entering into one product. It also provides for possible scrap and spoilage.

All the elements of cost involved in the use of the materials needed for a product can be analyzed, recorded, and filed for comparison with similar products and future study.

Make Material Specifications Known. In job shops each new job requires an estimate as a basis for the bid price. These estimates are filed for future reference and information. However, for products which are made in quantity it is wise to place the material specifications and amount needed, but not the cost, on the operation sheet. For large production jobs the material requirements often are studied several times to get the lowest possible minimum quantities per unit of product. Specifications for material are carefully analyzed to arrive at the lowest over-all cost, including labor and overhead. (See Chapter VI.) Thus the information is available for everyone concerned with the part and its materials. In Figure 5 is shown a typical method of placing this information on the operation sheet.

The materials come from Storeroom 229 and are delivered to Department 335. It takes 0.99 pound to make 1,000 parts. The number of pieces per foot of stock as well as the number of feet of stock per 1,000 parts is shown. The material also is completely specified.

Estimating Labor Costs. Labor costs per hour vary in different districts but the amount of labor used per unit of product varies tremendously within similar industries even in the same districts. The

petroleum refiner who found in a national survey that he was using 224 man-hours² per unit of product when his best competitor was using only 1 man-hour for the same unit of product was no longer in doubt of the reason he found it difficult to compete. Equipment, methods, and supervision are all important factors in the efficient use of labor and the relative costs per man-hour may be secondary.

Effect of Method on Labor Cost. Before anyone can estimate the amount of labor required, he must know or decide how the job will be done. The number of man-hours required to remove 2,000 cubic yards of earth depends on whether we use pick and shovel, horse-

DELIVER IN CONTAINER NO. 533			UNLESS OTHERWISE SPECIFIED.	
ISSUE 3/8/28		SHEET NO. SHEETS IN SET	NAME OF PART Spool Head	DRWG. P-98635
REPL. ISSUE 1/9/28			APPARATUS	
FROM STORE	QUANTITY PER 1000 PARTS	STOCK NUMBERS	PART NO. OR DESCRIPTION OF STOCK	DELIVER TO DEPT.
229	.99#	538763	.920"×1-3/32" In Coils Grade B Extra Hard Nickel Silver Sheet, Spec. 58210 84.53 pcs per ft. 1-3/32" wide 11.83 ft. 1-3/32" wide per M pcs.	335

Western Electric Co.

FIGURE 5. This type of information is often included on operation sheets.

drawn scraper, or a power shovel. Likewise, the number of man-hours to produce a quantity of special screws will depend on whether we use an engine lathe, hand-screw machine, automatic-screw machine, or a cold-heading machine with the threads produced by rolling. All these methods are in everyday use and each has its own economic limits. The job of the production control department is to understand the implications of these economic limits and to search for the best method by making cost comparisons. (Chapter IX, pages 154 and 163.)

Machine Performance Data. One of the first essentials for good labor estimating is a file of machine performance data. All production machines or assembly stations should be numbered and a separate card kept on file for each one. The cards should list essential dimensions of each machine and assembly place to show what range of work can be handled. Speeds, feeds, and productive rates should be listed in tabulated form. The capacity in impressions per hour for a printing press, in pounds per hour for a heating-treating furnace, or in pieces per hour for an automatic-feed punch press serves as an example of one type of information needed on the cards.

² "Measuring Operating Performance by the Kilo-Man-Hour," L. P. Alford and J. E. Hannum, *Mechanical Engineering*, Vol. 54, No. 12, p. 821.

Certain machines such as a drill press should list the various spindle speeds so that the estimator can select the proper one for his needs. Setup times for typical jobs should also be listed on these cards for each machine.

Effect of Skill on Labor Cost. The skill³ demanded for any job is generally a function of the method used. If a job requires, say, twenty-four table legs with rather intricate wood carving on each one, product analysis may use either hand carving or machine carving in multiple with the use of a master. The first method will require a highly skilled man while the second method can use semiskilled labor for everything except the final touching up by the skilled craftsman.

Skill requirements for factory jobs have been under fire by inventors, engineers, machine-tool builders, and others for over one hundred fifty years. There has been a reduction in the amount of skill required in almost all types of industry. Ever since the beginning of the Industrial Revolution the production of goods has been aided more and more by better machines, by better tools, and by better methods. The degree of skill required for any job in a modern factory is dependent on the degree to which the man is an adjunct of the machine. A machine loader or tender does not need much skill, particularly if special men are used to set up the machines.

In making up labor estimates it is important to use the correct grade of skill on each job. Not only are the less skilled workmen easier to

³ Skill is used in this discussion in its true sense as defined and used in technical literature. The term is often rather loosely used, and unless it is explained it is likely to be somewhat confusing. In most shops the workers are divided into two general groups, the skilled and the semiskilled. It is assumed that the skilled worker or mechanic can perform all the operations in one trade; the semiskilled man usually operates one type of machine such as turret lathes, drill presses, band saws, sewing machines, or other devices of which the operation is relatively simple and highly repetitive. Few unskilled laborers are now employed in factories. When they are, they form the lowest strata of workers, sweepers, truckers, and chip haulers.

Skill includes the varying degrees of judgment and manipulative dexterity in different combinations. Jobs requiring the best judgment and the most dexterity need the highest skilled workmen. Often skill is confused with proficiency. Skill of the highest order is necessary for the surgeon's work because he must use quick and excellent judgment, while at the same time he must be dexterous with the many tools of his profession. For the same reasons, a toolmaker also must possess considerable skill to build a complicated punch-press die. There are a number of modern tasks which require skill of a high order. On the other hand there are many thousands of occupations, particularly in those industries which have used the principle of division of labor, which require little or no skill; the man instead becomes proficient at his relatively simple task.

obtain from today's labor supply but also the wage rate per hour may be less.

Effect of Rush Orders on Labor Costs. Sometimes factories are asked to submit bids for work which must be rushed to completion. There are many ways in which goods may be produced faster, such as increasing the productivity of the machines, installing better methods, increasing the effort of each employee, increasing the number of hours worked per week with overtime pay, and adding more workers for the rush jobs.

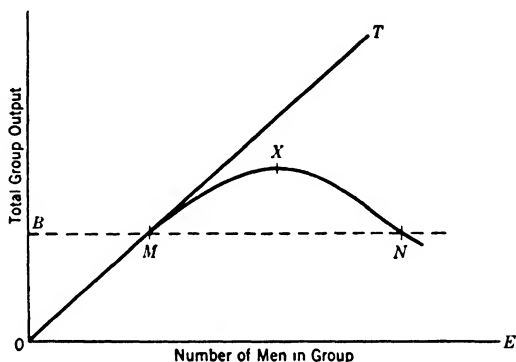


FIGURE 6. Law of diminishing returns as applied to number of men on a job.

Most of the ways to raise output mentioned above are subject to the law of diminishing returns.⁴ If they are carried too far the economic gain is exceeded by the economic loss incurred in trying for the gain.

An increase in the number of workers on a particular job does not always proportionately increase their total output. Figure 6 illustrates the trend graphically. If equal amounts of labor always gave equal increments of productivity the graph would be a straight line OT . Actually, however, the curve for most jobs would leave the straight line at some point M to give a decreasing increment of productivity for each added increment of labor up to a point X . Beyond X , each unit of labor added may decrease the productivity of the group until so many men are present at E that everyone is in confusion and no work is done at all.

This curve can be applied to many jobs. Each job will have its own curve but the trend may be similar for all jobs. Note points M and N on the curve. These are points of equal output for two groups

⁴ F. L. Eidmann, *Economic Control of Engineering and Manufacturing*, McGraw-Hill Book Co., 1931, p. 257.

of men. At point *N* the group is much larger and considerable money for wages would be wasted by placing this number of workers on the job. In times of stress, it may be expedient to add additional men until production reaches the point *X*, even if it costs more per unit of output than it does below the point *M*. However, it is foolish at any time to add men beyond the point *X* because outputs decrease as units of labor are added. The estimator should know where points *M* and *X* are for the jobs in the shop, to avoid mistakes in applying labor and its cost to a job.

Use of Operating Sheets for Estimating. As previously mentioned, it is necessary to know first how a job is to be done before any cost estimating is possible. The industrial engineering department, in conference with representatives from the design, planning, layout, tool, and production divisions of the plant, prepares operation sheets to show how each part or unit of the proposed product is to be made. These men decide on the operations and their sequences; they designate the machines and equipment which will be used; they select the available tools or authorize the design of new tools to aid in the production; and at times, for mass production, the plant layout is studied to give the best path for material flow. Rough estimates of the time for each operation are made. Rough sketches of the jigs, fixtures, and other tools are compared with their estimated costs to arrive at the proper economic methods. (See Chapters VIII, IX, and X.)

It must not be assumed that the tasks listed above are dashed off hurriedly. Enough time and work must be expended to do a good job. Mass-produced products are studied very carefully from every aspect of production. Small savings per piece become important when thousands of pieces are made. In job shops, production quantities are usually limited. Therefore proposed savings in cost on any operation must come from only a few pieces. This limits the amount of money and time which can economically be spent on operation study in job shops. Sometimes crude methods must be used in job shops because the next best method would cost more for tools and development time than the savings could justify.

During the time the methods and tools are being decided upon, rough estimates of costs are made to steer the discussion and point the way toward the ultimate decision. These estimates are seldom accurate enough to be used for making bids or setting sales prices.

After the thinking of the group has crystallized and the operation sheets or instructions are in written form, the labor time is estimated as accurately as possible.

Past Records and Labor Costs. If the piece to be made is similar to one which has been produced before, the available records of past performance may be usable. To be of any value, however, past records should clearly show the machine used, the kind and shape of tool material, the speed of the machine, the special fixtures and jigs used, and all other pertinent facts that may affect the rate of production. It is not safe to assume that all these factors affecting the rate of production were operating at maximum efficiency if they were not recorded at the time the record was made.

Analytical Method of Estimating Labor Costs. J. W. Hallock⁵ in his book *Production Planning* discusses a method of estimating time for an operation on machine tools which may be applied to a variety of jobs. It consists primarily of breaking up the operation into small elemental operations. The method presupposes a firsthand knowledge of the operation being estimated. It would be difficult, if not impossible, to estimate the time required for printing operations if one were not acquainted with the short cuts and tricks of the printer's trade.

The simple operation of facing a 6-inch pipe flange on an engine lathe illustrates a method which can be used in a wide variety of operations. A list of the detailed steps to perform the operation should be prepared with time estimates for each elemental operation. Some of the time estimates can be secured from a list of standard times for elemental operations which have been time studied in the shop. The actual machining time can be calculated by a simple procedure. The elemental operations with their estimated or calculated times for this operation are as follows:

1. Pick up rough casting	3 sec
2. Insert in chuck and true up	20 sec
3. Bring tool to position	10 sec
4. Throw in clutch	3 sec
5. Start feed	2 sec
6. Face flange	81 sec
7. Withdraw tool	6 sec
8. Throw out clutch	3 sec
9. Remove casting from lathe	15 sec
Total	143 sec

The only elemental operation which needs to be calculated is 6. The remainder can either be estimated by a knowledge of the requirements in the shop, or the figures may be taken from a table of times for elemental operations prepared by the time study department.

⁵ J. W. Hallock, *Production Planning*, Ronald Press, 1929.

Operation 6 above is definitely tied to the requirements of the drawing which shows the flange with an 11-inch outside diameter and a 6-inch hole. With a desirable tool life of $1\frac{1}{2}$ hours between grindings, a $\frac{3}{4}$ -inch high-speed tool should be run about 44 feet per minute for medium cast iron.

Effect of Assuming Proper Machining Speeds. It may be, however, that the available spindle speeds on the selected lathe will not give exactly the proper cutting speed desired. This is the main reason why it is necessary to have the actual spindle speeds or production rates of all machines listed on cards in the production control office. Usually it is necessary to use the nearest speed below the theoretically proper speed in order to have the necessary tool life. This often means that, unless we know the actual spindle speeds of the machines, we may assume the operation is being performed faster than the machine can work.

If the cutting speed on operation 6 is selected to be correct at the outside diameter it will be too slow at the 6-inch diameter. For purposes of estimating, assume an average diameter of $8\frac{1}{2}$ inches as the basis for figuring the cutting speed. The circumference then would be 2.2 feet and, with the 44-foot ideal cutting speed, the spindle should turn about 20 revolutions per minute. If the lathe has this speed available, the calculations would be as follows:

The lathe tool must travel horizontally over a distance of $5\frac{1}{2}$ inches minus 3 inches, or $2\frac{1}{2}$ inches, to face fully the flange. Assuming a feed of $\frac{3}{32}$ inch per revolution, the lathe must make

$$2\frac{1}{2} \div \frac{3}{32} = 26\frac{2}{3} \text{ (or 27) revolutions}$$

The time required to make this number of revolutions at 20 revolutions per minute would be

$$27\frac{2}{3} \div 20 = 1.35 \text{ minutes} = 81 \text{ seconds}$$

The estimated times in the elemental operation listed above do not allow for the various delays that may upset the operation. The percentage to allow for the delay factor will depend on how well the shop is organized and the working conditions. Ten per cent allowance for possible delays is sufficient for good shops but up to 25 or more per cent is necessary for poorly organized shops.

Detailed Analytical Studies Tend to Cancel Errors. It may seem to some individuals that it is easy to estimate a job without the detailed analysis. However, the errors tend to be greater if an entire job or any large portion of it is estimated without having been broken down

into elemental details. The errors on any details tend to compensate for each other.

Data for tables of elemental times similar to those shown in Lowry, Maynard, and Stegemerten's book on time study may be collected from actual situations in one's own plant; such tables are valuable in making estimates for future jobs.

Use of Standard Elemental Times to Estimate Production Time. The detailed analysis of elemental operations can be used to estimate production in a number of various industries. Modern practice in time study departments is towards the accumulation of tables of elemental times which may be used to set time studies without studying each operation in the shop. The use of such material is an excellent way to make accurate estimates and predict performance.

TABLE 1

PARTIAL TABULATION OF TIME ALLOWED IN HOURS FOR PERFORMING
OPERATIONS INCIDENT TO BORING MILL WORK

Operation	Size of Boring Mill in Inches			
	36 to 42	48 to 60	72	96 to 120
Get job drawing and time slip	0.1000	0.1000	0.1000	0.1000
Get tools and gages from tool room	0.1200	0.1200	0.1200	0.1200
Locate part	0.0044	0.0044	0.0044	0.0044
Get air hoist	0.0040	0.0040	.....	.....
Hook on part	0.0048	0.0107	0.0107	0.0107
Raise and place part on machine table	0.0173	0.0253	0.0253	0.0379
Release chain	0.0029	0.0029	0.0050	0.0050
Get chuck jaws, place in position and tighten	0.0242	0.0242	0.0242	0.0242
Get parallels and place in position	0.0086	0.0086	0.0086	0.0086
Study drawing	0.0187	0.0187	0.0187	0.0187
Adjust chuck jaws—per jaw	0.0064	0.0064	0.0064	0.0064

At the East Pittsburgh plant^a of the Westinghouse Electric and Manufacturing Company, tables have been made for time studies so that it is possible to estimate how long it will take for operations to be performed.

An analysis was made of each step or elemental operation required in machining a part on a machine. A partial list of such operations, for example, a boring mill, appears in Table 1.

^a "Estimating Time Required for Machining," *Machinery*. July 1937, p. 725.

The table should be complete with the time listed for all the elemental operations required for getting any job on and off the boring mill.

The time required for such operations as setting up and the actual machining will vary with the part's demands. To estimate these time factors, curves and tables are provided from which time for setup and machining may be read off directly.

Table 2 is calculated by the formula

$$T = 0.01955N \frac{L\pi D}{12FS}$$

where T = time in hours.

L = distance or length to be machined in inches.

D = diameter to be machined in inches (when calculating a facing operation, use mean diameter).

F = feed per revolution in inches.

S = surface speed, in feet per minute.

N = number of cuts that must be taken to remove required amount of material.

The constant 0.01955 is used to change the time from minutes to hours plus an allowance of 17 per cent.

$$\frac{1}{80} + \left(\frac{1}{80} \times 0.17\right) = 0.01955$$

TABLE 2

EXAMPLE OF TABLE GIVING UNIT TIME FOR BORING MILL OPERATION

Cast Iron—Continuous Cutting—High-Speed Steel Tools									
Depth of cut in inches	36- to 42-inch mill			54- to 60-inch mill			72- to 120-inch mill		
	S	F	C	S	F	C	S	F	C
$\frac{1}{8}$	47.5	0.080	0.00135	47.5	0.109	0.00099	42.5	0.250	0.00049
$\frac{1}{4}$	45.0	0.080	0.00143	47.5	0.083	0.00122	45.0	0.125	0.00091
$\frac{3}{8}$	45.0	0.062	0.00182	47.5	0.068	0.00159	47.5	0.094	0.00115
$\frac{1}{2}$	42.5	0.062	0.00192	45.0	0.068	0.00167	45.0	0.094	0.00121
$\frac{5}{8}$	40.0	0.062	0.00204	42.5	0.068	0.00177	42.5	0.094	0.00128

Table 2 shows the practical machining time allowance per inch for the length of the cut, per inch of the diameter to be machined. Col-

umn *C* contains the factor which, when multiplied by the outside diameter of the chip circle and the length of the cut, will give the hours required to complete one cut. This time includes an extra time allowance of 17 per cent for various delays. Thus the total machining time for any diameter and length of cut is easily calculated.

The Westinghouse Company has tables to include all the common materials of construction such as cast iron, cast steel, nickel-steel and others. Each material has a card for each of several different tool steels. In addition, each machine has cards showing results with or without lubricants, and with continuous or intermittent cuts. The estimating department at Westinghouse uses a large number of such cards for all the important machines. The boring mills alone have twenty-two different cards similar to the one shown in Table 2.

Tables can be prepared for almost any machine to show its rate of production. Extensive time studies should be made and all the various elemental operations should be listed with the necessary time allowance for each one. When a plant has sufficient work of a jobbing nature to warrant the collection and recording of such data, it becomes easy to estimate the time required for practically any machining operation even if the part has never been in the shop before.

Effect of Pacing on Estimating. Where the speed of production is set by some method of pacing the operation, the estimating of the labor costs is comparatively easy. The most common methods of pacing are (1) the use of a conveyer belt, which, as it moves, allows a definite amount of time for each operation and (2) the use of a machine that runs in automatic time cycles. The speed of a worker who feeds a printing press, for example, is controlled by the machine, but a linotype operator paces himself, for the machine can be run at high or low speed without interfering with the routine of any other worker. If a worker is paced by a machine the estimated output is a function of the machine's speed.

Estimating Setup Time. The cost of setting up machines should be included in the labor cost. Generally it is recorded as a separate item so that it can be given individual attention. The cost estimator should have standard setup times listed on the cards used to list machine capacities whenever this is feasible. For many kinds of operations, however, the setup time even on the same machines will vary widely from one job to another. For this, it will be necessary to record the standard setup time for each type of product on a separate card available in the files of the department, or to have a column on the operation sheet devoted to the setup time for each operation. When the operation is new and different and no precedent has been

determined for the setup time the estimator should consult with the foreman or key mechanic in the department.

Form for Recording Estimated Setup, Labor, and Burden Costs. In order to make an analytical estimate of labor costs, the cost of supplying man power for an operation and the cost of setting up the machine are recorded separately on a prepared form. Even where the shop does use operation or instruction sheets, it is advisable to use a labor cost estimating form along with a material estimating form (see page 255) to avoid the possibility of missing some of the cost items. Figure 7 shows a suggested form⁷ which provides the information necessary to do a good job of estimating labor setup and burden costs. The operations are shown in their proper sequence with the department number, setup labor, operating labor, and overhead cost itemized for each operation.

It is better to consider the burden for each department separately according to the number of hours the department is used. Departmental burden rates often vary considerably, and average rates do not give a true value to the costs. The setup and labor costs are subtotaled each time the part moves to a different department.

Setup times for ordinary jobs can be taken from recorded standards which have been studied in the shop. Unusual setups should be carefully estimated in conference with key workmen and production supervisors.

In Figure 7 the burden is calculated by multiplying the combined labor and setup cost by the burden rate for the department. The form can be used also for other methods of recovering burden charges. In any event the method of applying the burden for the cost estimate should be the same as the regular method used in the accounting division.

Burden Costs. Usually only the factory cost is considered in making cost estimates. This consists of the material and labor (prime cost) plus the factory overhead. The factory's share of the total overhead usually includes the entire cost of owning the factory buildings, machinery, and equipment. Such charges as depreciation, interest, maintenance, heat, light, power, janitor service, and all the other services and costs required to keep the buildings and equipment in first-class operating condition are items in the overhead cost. In addition the factory burden includes its share of the cost of using the facilities of the administration buildings and personnel. These administration charges may be distributed by the accounting division in several ways, but each department is called upon to carry some portion of them.

⁷ Adapted from the form on p. 1280 of *Cost and Production Handbook*, L. P. Alford, Ronald Press, 1934.

Some materials, such as steam for power hammers or processing, oil for heat treating, glue for furniture, and many others may be charged in the overhead for individual departments. The presence

LABOR AND BURDEN ESTIMATE FOR OPERATIONS ON																
For Customer or Dept.		Part Name	Part Number	1901	Drwg. No.	Date										
		10	10	11	11	1-15-42										
		Material			11 Gauge x 6" Hot Rod Steel Strip											
Dept.	Operation Number	Operation Name	Machine Name and Number	Set-up Analysis			Labor Analysis			Dept. Burden						
				Set-up	Rate	Cost	Dept. Subtotals	Output per Hr	Rate per Hr	Cost per M	Dept. Subtotals	Sum of Labor & Set-up	Dept Rate %	Burden Charge		
86	1	Set-up Shear	Shear No. 19	1/4	.50	.20										
86	2	Shear to Length	Shear No. 19					3,000	.60	.20						
86	3	Set-up Blanking Die	Bliss Press No. 57	1/2	.80	.40										
86	4	Blank and Pierce	Bliss Press No. 57					1,200	.60	.50						
86	5	Set-up Forming Die	Consolidated Press No. 42	1	.80	.80	1.40									
86	6	Form	Consolidated Press No. 42					600	.60	1.00	1.70	3.10	150	4.65		
22	7	Set-up Multiple Drill	National Drill No. 83	3/4	.60	.45	.45									
22	8	Counterbore Six Holes	National Drill No. 83					800	.48	.60	.60	1.08	125	1.31		
49	9	Twiddle to Remove Burrs	Twiddle Mill No. 10					1,000	.10	.10	.10	.10	80	.08		
52	10	Paint Drip	Paint Tank No. 204					500	.60	1.20						
52	11	Over Bole	Gas Oven No. 4					Included in Dip			1.20	1.20	250	3.00		
				Quantity to be Estimated			600 pcs.	Total Set-up			1.85	Total Labor			3.80	
				Set-up =			1.85	Total Labor			3.80	Total Burden			9.04	
				Labor =			3.80	Cost per			600	Pieces =			9.04	
				Burden =			9.04	Cost per			600	Pieces =			9.04	
				14.49 per M												
													Estimated by			H. J. R.

FIGURE 7. This type of form provides an orderly method of estimating labor and overhead.

or absence of such indirect material charges may make a large difference between overhead charges from one department to another as set by the accounting department.

Effect of Additional Tools Required. The costs of tools and special equipment generally used by the department are ordinarily in the department burden rate. However, it often is advisable to keep the

costs of tools and any other special preparations which must be included in the estimated cost for a new product as separate items. Even though such extra costs are actually a part of the overhead and will be so calculated after the estimated job is contracted, the sales division has an advantage when closing a contract if these extra costs are known. Sometimes the setup and tool costs make up a large part of the total cost; if they are specified in the estimate, the salesman often can sell more pieces to the customer to bring down the cost per piece.

Why Costs Are Itemized. Likewise the burden costs are broken down by departments to make it easier for those setting the selling prices or bids for future jobs. As the total cost is itemized, it is easier to meet stiff competition by knowing just where and how much the items may be adjusted to get the cost down. After some adjustment has been made, the estimator and the interested departments should be notified and the new work should be planned to meet the new estimated cost requirements. Burden charges are sometimes partially waived to obtain a needed order but such practice should be limited in the long run unless the burden can be actually reduced.

All Burden Costs Must Be Included. The charge for design and experimental work which may be necessary to make a specific order is a part of the estimated cost. Often, for job shops, this work is done by the customer and the shop has little or no expense for development work.

It is advisable to check the drawings and specifications carefully for close tolerances. Sometimes these are overlooked and it is discovered that extra costs to obtain the specified quality are far in excess of the estimated amount.

Moreover, the delivery date often has a decided effect on the cost of production. If speed is essential in the procurement of material, the extra costs of telegrams, express, and air shipments must be included in the estimate. Overtime wages are expensive and if used to excess the production per hour may go down, thus increasing the cost again. Extreme speed or heavy demand for short periods may lead to uneconomic expansion of facilities which later cannot carry their share of the overhead when business drops off. Overhead charges may be distributed differently as extra shifts and overtime are applied to affect plant capacity. The estimator should consider many things which have a bearing on factory costs to avoid losing profits, orders, or both.

Form to Record Summary of Costs. To aid the estimator in presenting the several items of cost to the persons setting the sales prices, the

FORM TO RECORD SUMMARY OF COSTS

255

**TOTAL ESTIMATED COST OF MATERIAL, LABOR, AND BURDEN
FOR**

[illegible]

form⁸ suggested in Figure 8 is used where more than one part or piece is estimated. The costs of material, labor, and burden as itemized and totaled in Figures 4 and 7 are entered in Figure 8 to provide the total cost for all the parts of a certain product. The cost of additional tools for each product should be estimated as if they were products in themselves. The itemized costs of materials, labor, and burden for the additional tools can then be summarized on the suggested form shown in Figure 8.

Organization for Estimating. The organization of the estimating department depends on the types of products manufactured, the size of the plant, and the method of manufacturing. The estimators cannot be independent of the rest of the plant. Their success or lack of it depends entirely on the cooperation and coordination which is existent in the whole plant. Poor supervision, carelessness of the workmen, or other wasteful practices can undermine the most careful estimates.

In some plants the estimators work under the jurisdiction of the engineering design or the sales department, but more generally it is advisable to have the estimating function performed under the auspices of the production control department. Estimating presupposes planning in some measure. It should be supervised and nurtured by the group who are responsible for the planning when the bid is finally accepted and the product is ready to enter the shop.

Qualifications for Estimators. An estimator should be very carefully selected for this important job. Only men who have had years of production experience, preferably augmented by technical training, should be considered for estimating work. They should have excellent judgment, should be able to analyze shop processes and problems, and should have a flair for careful detail work which must be accurate. An estimator works with detail, yet it is not like the detail of the clerk. He must have native ability and initiative; he must be foresighted enough to predict successfully production; he must come up with the right answer and must have the judgment to recognize the right answer when he sees it.

QUESTIONS AND PROBLEMS

1. Compare the factory f.o.b. prices of five of the lowest-priced, similar body model automobiles during the last three years. Compare the price per pound. Could this be used as a basis for a rough estimate for pricing new models?

⁸ Adapted from form on p. 1282 of *Cost and Production Handbook*, L. P. Alford, Ronald Press, 1934.

2. Why is cost sometimes a poor basis for price?
3. How can an estimator arrive at costs which may be used as a basis for price?
4. When can material records be relied upon for estimating purposes?
5. What factors may cause bids from different shops to vary widely for the same job?

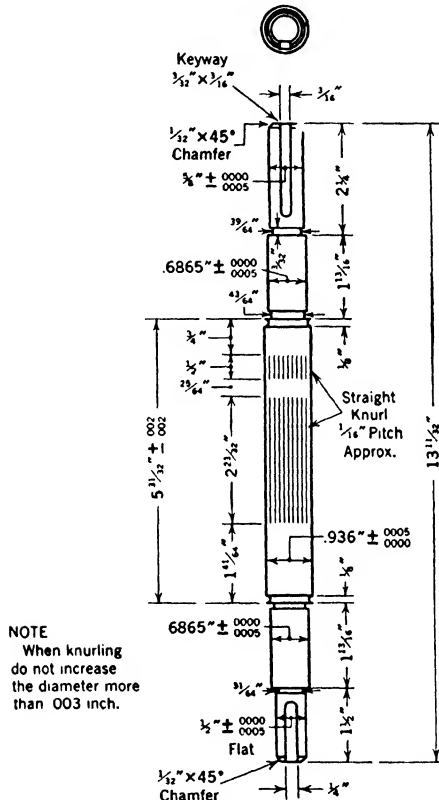


FIGURE 9. $\frac{1}{2}$ -horsepower induction motor shaft.

6. Estimate the cast iron which must be melted to make 1,000 bearing brackets. See Figure 15 in Chapter XI.
7. Estimate the material needed to make 1,000 stampings as shown in Figure 2. Show sketch of how material would be placed in die.
8. What effect would method have on the man-hours required to produce the thread on 10,000 $\frac{1}{2}$ -inch cap screws, 2 inches long?
9. Gather the data to show the productive capacity of (a) a small drill press, (b) a sand muller, and (c) an engine lathe.
10. What effect would method have on the skill necessary to make (a) a pair of dress shoes, (b) a book, and (c) a pound of fancy chocolate candy?

11. Draw a curve to show the law of diminishing returns when men are added to shovel snow 1 foot deep from 300 feet of 6-foot sidewalk. What is your estimate of the optimum number of men to get the job done as quickly as possible?

12. Draw the same kind of curve as in Problem 11 for unloading a boxcar load of 2-inch by 12-inch by 14-foot planks and piling them into standard piles on one side of the track within the length of the car.

13. Estimate the turning time for the motor shaft in Figure 9, by the elemental operation technique.

14. Estimate the machining time for the bearing bracket by the elemental operation technique. See Figure 15, Chapter XI.

15. What effect does pacing have on cost estimating?

16. What effect does setup time have on cost estimating?

17. How should the cost for special tools required for a job be used in making a cost estimate?

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CHAPTER XIII

INSPECTION

Inspection is the technique of controlling a predetermined quality standard. Inspection methods have been developed for innumerable activities of all kinds. State laws often require inspections of grain, gasoline, and gallon measures. Grain and gasoline are inspected to enable them to be placed in one of a number of grades, each with its own standards. The gallon measure is inspected in the United States to determine if it conforms to the one standard gallon. In some localities farm products are inspected for pests before the products may cross into certain quarantine zones. Some states require a medical inspection of one or both people entering into a marriage contract. All peoples and lands are familiar with inspections of one kind or another and it has become an important activity of the modern world.

This chapter is particularly concerned with some of the typical problems involved in the control of the quality of manufactured articles. Regardless of whether the factory produces soap, soup, axes, or automobiles, the essential problem of trying to maintain the quality of the product is the same. Before any manufacturing or inspection can be done, someone must determine the standards of quality which are to be used.

The fundamentals of good specifications are, first, a knowledge of all the necessary physical properties and allowable tolerances. Second, these requirements should be stated in such clear and concise words that only the correct interpretation is possible. If the requirements are correctly determined but poorly described or expressed, the meaning may be distorted by persons who do not interpret the words correctly.

What Is Quality? To some individuals, quality is a vague term which is loosely described as the "best." This specification, though it may be useful for certain types of advertising and sales work, lacks value as a standard for manufacturing or inspecting.

Other individuals think of quality as an absolute thing measured by absolute standards. Strangely enough, sometimes the crudest of standards are mistaken as absolute by certain grades of workmen.

The rough carpenter may measure a board with his loose-jointed, 6-foot folding rule and declare the board is exactly 10 feet long. On the other hand, many blueprints and specifications have been placed in the shop with dimensions or weights written to the fourth decimal place, with no tolerances expressed.

The carefully trained individual will declare a certain gage block is 2 inches long with a possible plus or minus error of one millionth of an inch at 68 degrees Fahrenheit. This production-wise individual insists on tolerances for all quality standards. He knows there must be a certain distance between the quality limits for all the goods of commerce. Certain rare, highly scientific instruments and devices sometimes have tolerances exceedingly small but even here the desired absolute values are seldom reached.

Tolerances Are Necessary. The layman or crude workman thinks an inch is an inch but to a carefully trained inspector an inch is never exactly an inch but always plus or minus something.

There is no point in making the bull's eye of the target smaller than the diameter of the bullet. On the other hand, the larger the bull's eye can be made, the greater chance there is for a person to hit it at a given distance. Maintaining a certain quality for a manufactured article has much in common with target shooting. The aim may be perfect and the target may be brilliantly lighted, but many unknown and chance events may influence the final score. Likewise, quality standards may be the target but if the bull's eye of tolerance is too small the production score is going to be lower than necessary.

The determination of tolerances is further complicated by the very gages used to measure them. Gages cannot be made exactly alike. Some tolerances, however small, must be allowed in making them and thus if two or more gages are used they never can be exactly the same size. Moreover, after a gage has been used for some time, wear occurs on the gaging surfaces which must be considered for close work. This wear tolerance is determined so that when the maximum allowable wear has occurred the gage is readjusted or discarded. Another variation in gaging occurs with certain gages, such as the snap variety, because of the personal differences in judging when the gages fit.

Some of the newer types of gages have largely eliminated most of these difficulties by constant pressure applied at the gaging points. Adjustable gages are also replacing the older solid type to reduce the wear problem.

All gages used for close measurements should be checked periodically. The intervals between checks depend upon the importance of the gaging operation, the amount of use, and the rate of wear. Some

gages should be checked at least once a day or oftener, but many can be in service several weeks or months before they need adjustment. Card files to show the history of important gages will aid in the determination of time intervals between gage inspections.

Definition of Quality. It is quite difficult to define quality because it is comparative and can rarely be made absolute. That is, quality may be better or worse than some arbitrary predetermined standard. The highest grade coal for some situations may be any coal which contains over 14,000 Btu's per pound. But if the coal is to be used for certain metallurgical purposes, the highest grade coals suitable for this service would probably be further limited by requirements of coking qualities and low sulfur content.

Many characteristics may be included in definitions of qualities for different specific uses. Machinability, hardness, finish, ductility, workmanship, size, design, stability, color, and dozens of others may be important enough to affect the quality of the final product. Some of these elements of quality are primarily important in the design, appearance, or usefulness of the product. This aspect of quality affects the sales or intended use of the article. That is, a well-designed wheelbarrow mounted on rubber tires, with aluminum frame and hopper and with antifriction bearings, must be compared for quality with other wheelbarrows or similar devices, and not with dump trucks, drag-line buckets, or other mechanized material handling equipment.

Another aspect of quality is concerned with how well the products agree with certain standards such as weight, color, taste, lineal or angular measurements, and other physical standards of quality which have been set for the product. In a manufacturing sense, the inspection to determine this conformance to such set standards constitutes the main job of the inspection department. Regardless of how thoroughly the inspection function is organized, however, it can never create the desired quality; inspection controls quality by using certain techniques. Quality is conceived in the design, is given substance in the properly chosen materials, and assumes form in the various plant operations. If the production departments are furnished with a good design, suitable materials, and adequate production facilities, they must be held responsible for creating a quality product.

Responsibility for Quality. The production worker and his foreman then are directly responsible for the quality of the goods produced. Workmen must be cautioned to examine or measure their work frequently as it is processed through their work stations. No inspector can substitute his ability for the creative ability of the good mechanic.

In some quarters there is a feeling that, when large-scale production comes in, quality must be sacrificed to obtain high production. Generally, however, the large-scale use of special, accurate fixtures, jigs, and dies to get the high production is also conducive to the manufacture of first-class quality materials. These special tools are originally designed to produce goods to meet the desired standards of quality; and by a maintenance and replacement policy, these tools can continue to produce to the same standards indefinitely. Practically any of our mass-produced articles of commerce, such as the automobile, washing machine, radio, and many others, are now made with higher standards of quality than ever before.

INSPECTION FUNCTIONS

The inspection department in a modern plant should be responsible for the control of quality from the raw material to the final inspection of the finished product along with preparation of adequate condensed records to guide management toward better control.

Whenever there are properties to be developed in the product, which depend on close control of temperature, humidity, light, pressure, voltage, or any one of the other processing aids, the inspection department or process control department often is asked to keep records of instrument readings. Recording instruments are being used more and more for this work and automatic controlling mechanisms are sometimes used.

Inspection for Preventive Measures. The major functions of a good inspection division are primarily concerned with such controls and they include, first, a method of working cooperatively with the production and engineering departments to find the primary cause of scrap where it is assignable. Castings, for instance, often have defects which cause large scrap losses because of faulty design. The design may call for sudden changes in section thickness and thus cause casting shrinkage problems. The type of casting desired may not allow sufficient support for the cores which may permit core shifting with all its attendant evils. Clearances should be given major consideration in the development of the design of a product. Designers should allow the greatest possible amount of clearance between companion parts. The more tolerance which can be permitted and yet give the desired technical operating conditions, the greater the economy of manufacture and the greater the degree of interchangeability.

In addition to difficulties of quality control due to the original design, the production department often needs to find ways and means

of eliminating scrap due to faulty manufacturing techniques. If a foundry molder does not place the pouring gate in the right place the casting may have serious defects. Sometimes by a change in the sequence of a series of operations the percentage of scrap may be reduced or the amount of labor expended may be less before a defective casting or forging is found.

Many companies with complicated inspection problems have a special group of men who are interested in the development of better inspection methods and equipment. It is their duty to keep the company's inspection policies abreast of advances made elsewhere and to develop new gages and other inspection devices when needed.

As production schedules increase in any one plant, it usually is necessary for the inspection development people to devise inspection methods which can operate faster and more cheaply and still be effective. Otherwise, it would be difficult to get enough people of the proper caliber to inspect the thousands of parts in a high-production plant by the ordinary inspection methods. Even if the people could be found, the wages of such personnel would increase the cost of the product so that its economic usefulness might be impaired.

One of the important duties of the development branch of the inspection division is establishing and maintaining the necessary quality, and one of the most difficult of their tasks is educating the rest of the manufacturing division to the desired standards.

Example of Preventive Inspection. The National Cash Register Company,¹ which has worked out a plan for controlling the quality of over sixty-seven thousand separate parts, uses a preventive measure by checking a sample of the first lot of each new or changed part before it is released for routine inspection. All the gages to be used in the routine checking of the part are carefully examined at the same time. This section of the inspection division is detached from the remainder of the inspection division and reports directly to the chief inspector.

When a new part fails to meet the standard specifications, an investigation is made to determine whether tools or workmanship are to blame. The blame is recorded for the inspection file, the parts' identification tags are marked rejected, and the defective work is returned to the shop.

If the error is due to the tools, a red rejection slip is made out in triplicate, one copy is sent to the interested shop along with the de-

¹ "Inspection—Checking Department Controls Quality of Work," C. E. Stines, *Machinery*, June 1938, p. 670.

fective work, another goes to the tool inspection department, and the third copy is retained by the inspector. This inspector's copy is filed until the second sample of the work appears for inspection, after the tools are corrected. If the part is then correct, it is released for production and regular inspection.

This method of check-inspection prevents defective work from being produced in large quantities on new jobs before parts and tools are thoroughly checked and found to be satisfactory.

It usually is not possible to place all the necessary dimensions on one drawing to construct, for instance, the patterns, tools, gages, and the part itself. Certain dimensions can be correct if one set of locating and holding points was used, but they might be incorrect if the part were held and located from different points. It is impossible to amplify this point without expounding on the effect of different location points for holding parts in the manufacturing process, but it is sufficient to say that some manufacturers solve this problem by using operation drawings which give only those dimensions that are required at a specific operation. Thus, the information required at each point of manufacture can be placed on that drawing without fear that it will be misused as it might be if it were placed on the one main drawing. Mistakes in the proper dimension for any operation are lessened by such preventive measures.

The preventive type of inspection may be called one of the highest types of work in the inspection department. It is the one function of inspection which pays the most dividends for the amount of money expended.

Preventive inspection techniques are becoming increasingly important in modern industry and as they become more effective the need for the other functions of inspection diminishes.

Inspection for Finding Defective Goods. The second important function of inspection is to devise procedures to check the quality of the product at various stages of its processing. Some concerns inspect only the final product, whereas others, manufacturing more exacting products, carefully check at a number of points to insure a good product and to prevent the expenditure of more labor after the part has become defective.

Raw materials are the starting points for most productive processes and they should have the proper specifications to satisfy the standard required. Various technical societies and public bureaus have issued standard specifications for many kinds and grades of materials. These specifications are becoming more useful to industry as more and more plants are incorporating them into their design standards.

Vendors of materials thus are able to manufacture their products to a fairly definite group of specifications which in turn are then accepted by the users as the known best for the purpose. This standardization of specifications is a progressive study. It is being extended to new fields and it must be amended from time to time to include newer and better materials and to eliminate others which are becoming obsolete or unsuitable as compared to the newer materials.

Raw Materials Inspection. It is one thing to purchase materials by specifications, but it is quite another problem to be sure the materials fill the specifications when they arrive. Even where vendors have an excellent reputation for careful adherence to the required specifications, the possibility of short and, incidentally, long counts is always present. Few vendors are so organized that miscounts and wrong billing are impossible. Human errors occur even in the best companies and the users of the product usually should be ready to check it. Investigation of one company's records over a long period did reveal, however, that some of their vendors made both plus and minus errors in quantity which tended to equalize themselves. For the honest buyer, who reports both long and short counts, it would be a waste to check the counts with such known vendors.

The inspection of raw materials to insure the proper physical properties is a widely divergent function with many different techniques and types of equipment necessary for the testing problems. Some companies have resident inspectors in the vendor's plant who exercise both preventive and condemnation inspection on materials destined for their employer's plant. This procedure saves freight on defective material and insures better material at lower cost.

Sometimes the vendor runs into difficulty in trying to make parts or materials as specified. He takes the problem back to the buyer where the inspection, production, and engineering departments' experts try to help him find a solution. Various suggestions are weighed and tried to find some method of producing the right material for the job. If the first vendor finds it is impossible to produce the proper material for the job, the purchasing agent has to find another source of supply.

In some simple material inspection, visual examination is sufficient. For more stringent specifications, however, it may be necessary to have extensive laboratories where various chemical, thermal, electrical, physical, mechanical, or metallurgical tests can be made. For small companies that cannot afford laboratories there are commercial laboratories available for such work.

The cost of a complete inspection of raw materials is often prohibitive and the work is usually done by a sampling procedure. Sampling, of course, requires knowledge of the production process by which the raw material was made, and the record and integrity of the vendor also have an important bearing on the sampling procedure.

Specifications for materials are becoming more technical, more selective, and more numerous as industry learns more and more about production. The general tendency is shown by the quotation ² below.

It used to be that steel was pretty much standardized. There was a time, when, for example, a product called full-pickled, full-cold-rolled sheets existed. From these were made automobile doors, body panels, hoods, fenders, and cowls. Today there is no such thing as a general product for automobile bodies. Our engineers, and the engineers of our competitors who also serve the automobile makers, go out into the automobile plants and determine the qualities that a steel must have to do a given job. There are, for instance, fenders formed to such difficult shapes that they require a very special fender steel. A given part of one car requires certain qualities to be formed most economically by the presses, the same part of another car requires a different set of qualities.

What this means to the steelmaker in engineering service, in laboratory experiments, in the actual operations of his plant can well be imagined by any production man in any industry. It has brought about so great an addition of personnel that, despite the development of continuous rolling, we today employ 1.57 men per 100 tons of steel shipped, whereas in 1923 with much less efficient production methods we employed 1.36 men per 100 tons shipped. This, incidentally, is an excellent commentary on the apprehensions of the free-for-all worriers who feel that technological process is responsible for unemployment.

While we have been improving our processes and our service, we are getting \$62 per ton for automobile fender sheet as compared with \$135 per ton in 1923—46 per cent of the price of 15 years ago. And we suspect that this situation is typical of a large segment of American industry.

Process Inspection. After the shop has had the proper raw materials supplied to the various operations, it becomes the shop's responsibility to produce the product to the manufacturing standards of quality. Process inspection is generally used here since it is primarily intended for catching defects which have already appeared. They should be caught as early in the process as possible to eliminate fur-

²"Management's Job—As I See It," Charles R. Hook, *Factory Management and Maintenance*, Vol. 97, No. 7, p. 39.

ther waste of labor on the spoiled work. As the spoiled goods are found, the employee responsible for the scrap is usually required to rework the parts, if this is feasible.

The first few units of a new lot should be inspected by the foreman and an inspector, if roving inspectors are used. This insures that the machine is correctly set up and that the operator understands his instructions for the operation and the tolerances allowed. After this initial inspection, the process should be checked from time to time to find possible maladjustments in the machine or changes in the material. The extent and frequency of process inspection will depend a great deal on the size of the tolerances allowed, the skill and experience of the workmen, and the excellence of the machine and tools used. In certain mass-production operations, the machines continue to produce enormous quantities of goods of high quality with only a minimum of inspection necessary during or after the process.

Types of Process Inspection. Materials in process are inspected for various qualities, such as the physical properties, the form or dimension, and the degree of finish. Physical properties may refer to the degree of hydrogenation of an edible fat, the hardness in Brinnell, Rockwell, or Scleroscope numbers, the degree of legibility of a printed page in a printing plant, or the carbon content of the cast iron being produced in a foundry. Various process controls are used to keep the desired physical properties constant, but occasional checks are still necessary to insure uniformity due to chance events which may affect the quality.

Most metal-, wood-, and plastic-working shops are concerned with quality as expressed by form or accurate dimensions. This type of inspection is intimately associated with the entire subject of fits, tolerances, limits, clearances, and interchangeable manufacturing. Several technical groups such as the American Society of Mechanical Engineers and the Society of Automotive Engineers have proposed the standard limits for various types of fits required in different kinds of machinery. These limits vary widely according to the product and the service to be rendered. A wheelbarrow never requires the same tolerances on its dimensions as does even the cheapest watch. The selection of the proper tolerances is largely the responsibility of the engineering design in cooperation with the production departments.

The tools, gages, and other equipment used to inspect form or dimension are the most common inspection devices. Some of them may be very elaborate or very simple, but the primary principles of testing a curved line for conformance to a standard form or measuring the length of a straight-line dimension are usually quite simple.

Standards of finish and color are becoming easier to measure owing to improved instrumentation. Color meters working on the spectroscopic principle now are available to give arbitrary numbers to hues and shades which can in turn be checked by comparing the unknown color with the standard color number. Surface meters for checking the degrees of finish are also available in several types. Some depend on reflection from the surface and others depend on a needle passing over the surface to record the imperfections by vacuum-tube amplification techniques. Cracks or surface defects in ferrous metals may be detected by magnetic flux methods which arrange fine powder in patterns around the defect. There is still room for new and improved instruments to measure the quality of various metal-plating work, wood finishes, and other standard finishing methods.

Final Inspection and Testing. Practically all concerns inspect the final product before it is shipped, whether any other inspection of unit parts is made or not. This final inspection may be for appearance. For example, silk hose, cloth, or fancy candy may be rejected as first-quality merchandise but may be sold under a cheaper brand name or plainly marked second grade. Meat products are commonly sold in different grades largely determined by age and quality of the animal in the first place, and by inspection where bruises or other imperfections may damage the otherwise first-quality meat.

Mechanical equipment is generally given an operation test which usually exceeds the requirements of the actual user. These performance tests should be standardized so that all units are tested to the same degree. A prominent manufacturer of an automatic toaster tests every machine by actually toasting bread under controlled conditions. Any machine which does not perform satisfactorily under these conditions is sent back to the shop for adjustment or repairs.

Process Inspection Example. The manufacture of sixty-seven thousand different parts for the various machines made by the National Cash Register Company,³ requires a large force of inspectors. One person out of every fourteen factory employees is an inspector in a comprehensive system which aims to prevent the manufacture of defective work rather than to find defects when the work fails to meet the quality requirements.

All machine operators are provided with the gages and measuring tools needed for them to inspect the current job on the machine. The operators are cautioned to make periodic inspections and time is

³ "Controlling the Quality of 67,000 Different Parts," C. E. Stines, *Machinery*, August 1938, pp. 825-826.

allowed for this when wage incentives are set. As far as possible, the operators are held responsible for any defective work. Whenever a machine is set up on a new job the foreman must approve the job before production can be started.

Process inspection is performed both on the factory floor and in special centralized inspection rooms. About 25 per cent of the parts are inspected in the production departments, on conveyer lines, or between successive operations.



National Cash Register Co.

FIGURE 1. Fixture specially designed for inspection.

The inspection equipment consists of the usual run of "go" and "no go" gages, contour gages, and comparison gages. For close measurements an amplifying or optical gage is used. To make inspection easier and cheaper for some parts, many specially designed gages are used. Figures 1 and 2 illustrate special gages designed to test the parts shown near the gage.

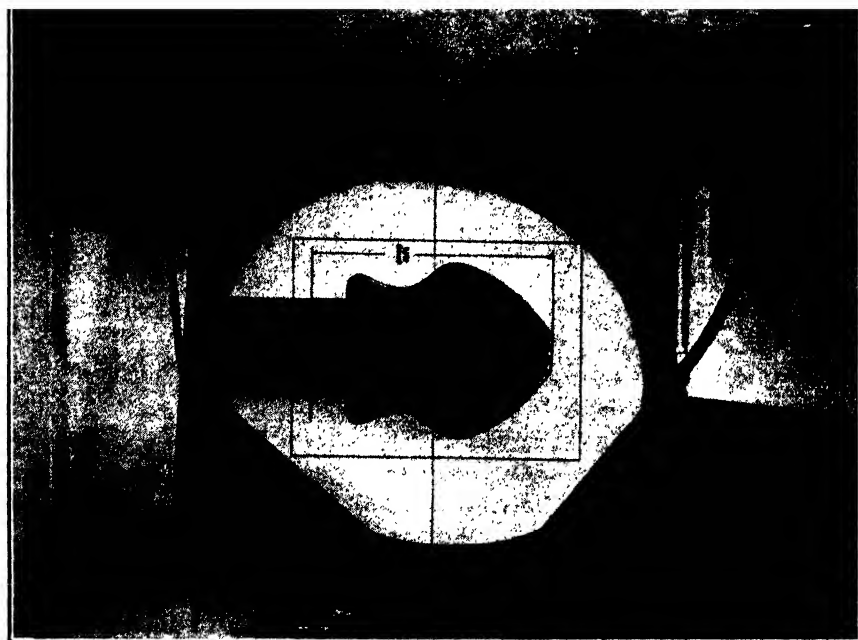
Where contours must be accurately checked, an optical comparator is used to magnify a shadow cast by one part and to compare it with an enlarged drawing of the part. (See Figure 3.)

Each tote pan of parts has an identification tag which among other things is a key for locating the instruction card filed in the inspection



National Cash Register Co.

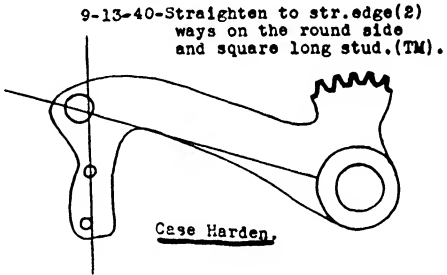
FIGURE 2. Dial-type inspection fixture.



National Cash Register Co.

FIGURE 3. Optical comparator for contours.

department. An inspection instruction card has been prepared for every inspection operation on each part. The inspector is not permitted to rely on his memory for what should be inspected. Formerly, verbal instructions and memory were trusted to get proper inspection, but defective work frequently was passed and it was difficult to fix responsibility for the resultant loss. At the present time, the inspection department has 80,000 inspection cards on file, all of which have been written in the inspection offices.

EFFECTIVE INSP. _____	2000 Detail Feed Shifting Segment "B"	89179
F-2860 A-F21W	A-39803	1-20-41
59A-305f	Depth Gauge -	Drill#1
59B-41f	Str. & Squaring Block-	Assem "C"
375y	<u>Research Note of 6-3-40</u>	
121rz	<u>12-29-40 See that large stud is not loose.</u>	
391y	<u>Test Stud for copper braze.</u>	
129y	<u>5-14-40 Check hub with .4375 receiver.</u>	
62f		
402-63fz		
11-7-551z		
51y		
2fz		
26b		
VB		

National Cash Register Co.

FIGURE 4. Inspection instruction card.

The instruction card carries enough data and instructions to show all the points to be inspected, and sketches are used wherever possible to show where operations are to be performed. Tolerances are given on the various requirements. In Figure 4 the inspector is cautioned to check the stud for tightness.

The inspector writes his check number on the back of the instruction card with the date and number of pieces passed. Responsibility is fixed and all disputes caused by lack of information are eliminated. Moreover, the inspection cards speed up the inspection time per lot, because they eliminate the necessity of waiting for instructions.

The information on the inspection cards is also used on the operation sheets issued by the production control department, so that the

INSPECTION

operating department can know in advance what the inspection requirements will be. Figure 5 shows an operation sheet used by the National Cash Register Company. The operations on this sheet are

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National Cash Register Co.

FIGURE 5. Operation sheet with some information in code.

designated by code numbers and symbols. Note that the explanation of symbols designates 26B as an inspection operation. The other operations are also listed and explained. The time study department uses the same information on the operation sheets when establishing standard times so that the necessary inspection time can be included.

Following is an explanation of the letters and numbers appearing on the instruction card and stock card, with letters designating departments doing the work and numbers the operations being performed.

59A-305f	59-wash-305 ringstake, "F" designates assembly "F" department.
59B-41f	59-wash-41-rivet, "F" designates assembly "F" department.
375y	375-braze, "Y" designates heat treating department.
121rz	121-strip, "RZ" designates plating department.
39iy	39-ream, "IY" designates drill # 1 department.
129y	129-case harden, "Y" designates heat treating department.
62f	62-lapp, "F" designates assembly "F" department.
402-63fz	402-straighten to straight edge, 63-square, "FZ" designates assembly "G" department.
11-7-55iz	11-drill, 7-co-bore, 55-tap, "IZ" designates drill # 1 department.
5iy	5-burr, "IZ" designates drill # 1 department.
2fz	2-assemble, "FZ" designates assembly "G" department.
26b	26-inspect, "B" designates inspection "B" department.
VB	"V" designates stock, "B" designates department. (Stock "B.")

All rejected stock is returned to the responsible department so that rejections can be brought to the attention of the foreman and operator concerned. Figure 6 shows a form used by the National Cash Register Company to cover rejected work.

Inspectors have no authority to make any exceptions to established standards. Exceptions can be made only by the inspection foreman and then in most cases only with the approval of the design engineering division.

Counting and Recording Function of Inspection. Inspection often is called upon to do more than control quality. During the routine inspection operations, the quantity as well as the quality is checked at various points. The inspector's report to the dispatcher serves as a progress report and as a check on the number of pieces completed in the lot. If scrap is excessive, the dispatcher can notify the planning department that the lot is short and proper measures can be taken from that point. Moreover, the counting procedure can be used as the official count of good pieces for any wage incentive payment and for posting the inventory control.

The inspection report should analyze the causes of failure and suggest ways of eliminating it. Inspectors are peculiarly adapted by their position in the organization to give important information and criticism to foremen and production control executives. A good inspector can have his finger on the pulse of a department and can detect when production is lagging, quality is decreasing, or scrap is becoming excessive. Such reports to the chief inspector can be incorporated in

the department's report to give unbiased constructive criticism which is directed at improvement of production facilities.

Centralized versus Decentralized Inspection. Inspection may be actually done in one or more centralized locations, first, where the units to be inspected are transported to the location and, second, where the inspector may move to the work place for the inspection. Decentral-

THE NCR REOPERATION AND REJECTION TICKET			
Mill	Dept.	1-20	19 41
Page No. <u>E-89179</u>	Name of Part	<u>C-2000 Detail</u>	
<i>Feed Shifting Segment "B"</i>			
<u>350</u>	Pieces out of	<u>350</u>	Inspected
are rejected returned for operation		<u>XB-15 p</u>	
Caused by		<u>Burr in teeth from straightening</u> (Charge to Assembly "G")	
Per Cent of Stock Returned		<u>100%</u>	
Workman's Name		Check No.	<u>209</u>
Time Allowed		Inspector	<u>041</u>

Box Nos.	Original Box Nos.	
E		<div style="text-align: right; padding-right: 20px;">Inspection Dept.</div> <div style="text-align: right; padding-right: 20px;"><u>G. H. Swaninger</u> Foreman</div> <div>By <u>Hall</u></div> <div>Received the above stock</div> <div style="text-align: right; padding-right: 20px;"><u>CAK</u> Foreman</div>
50025		

National Cash Register Co.

FIGURE 6. Defective parts report.

ized inspection may be casual or thorough, depending on the product. Usually the roving inspector can reduce transportation and process inventory charges. Operations can be scheduled closer together if no time is needed for transportation to and from the inspection booth. Moreover, possible defects may be found during the frequent visits of the inspector to the work place. This prevents a further waste of material and labor.

On the other hand, the roving inspector usually must be a higher-grade man, both in his technical ability and in his ability to get along with the workmen. The operators of all the machines served by the roving inspector know him, and this may not be good either for future

quality or peaceful relations, both of which depend upon personalities.

In line production or where large heavy units are being processed it is not expedient to move the parts to a central place. Inspectors necessarily must check the parts on the shop floor at frequent intervals for line production and after certain operations for large units.

Centralized inspection has some advantages which should be studied from a cost standpoint to determine its feasibility. The central in-

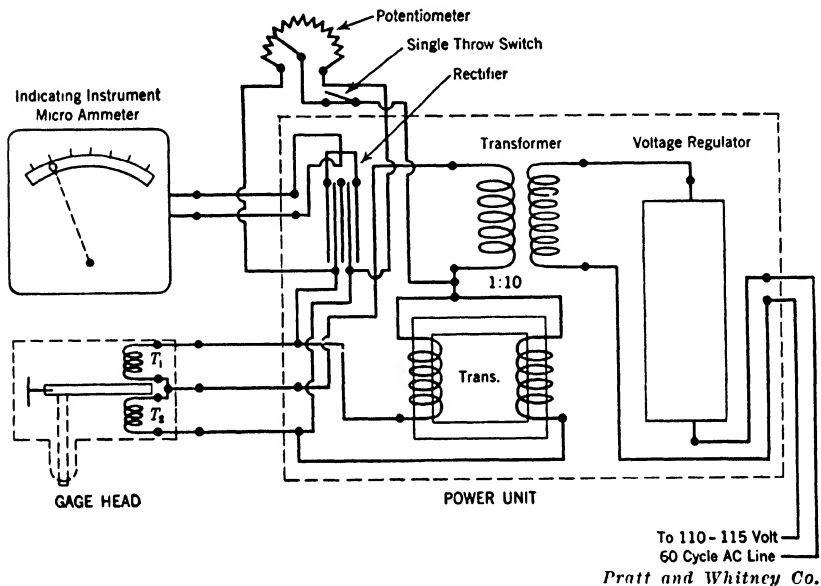


FIGURE 7(a). Circuit diagram for electrolimit gage.

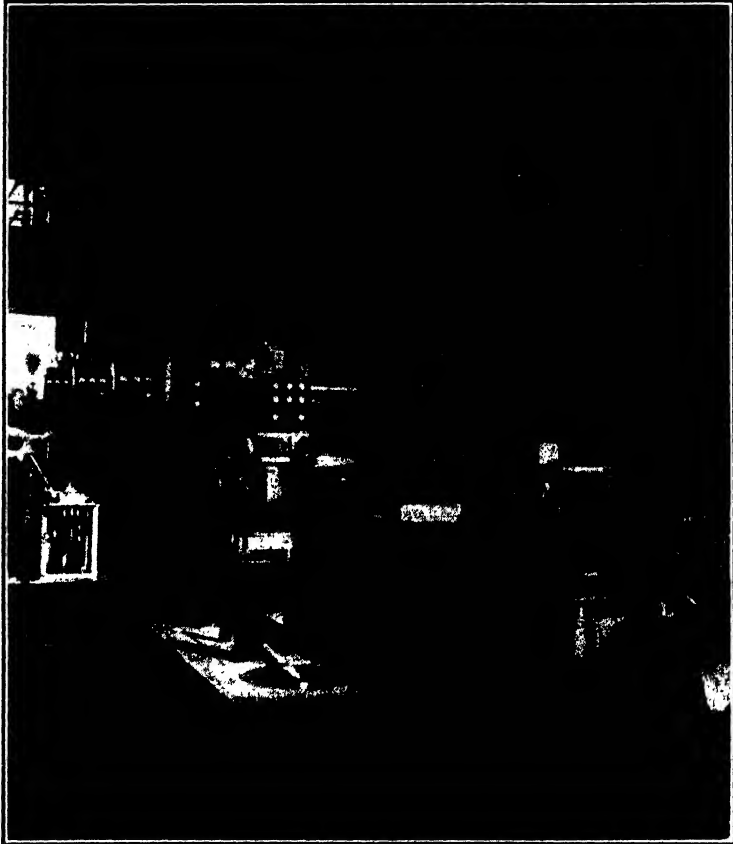
spection place or booth is usually specially equipped for the purpose. Inspectors may be less skillful if the division of labor principle is used to speed the learning process and the actual inspection time. Central inspection facilities may be much more complete and effective due to the use of special delicate equipment which cannot be easily or carelessly moved about. There is less confusion in a place where all workers are doing about the same thing, and records are apt to be more complete and accurate.

Most plants use both centralized and decentralized inspection to cover completely all phases of the inspection problem.

Examples of Special Equipment for Inspection. The American Gage Design Committee,⁴ which is made up of representatives of govern-

⁴ "Gaging Equipment in Modern Industry," A. H. d'Arcambal, *Machinery*, December 1937, p. 248.

ment, gage users, and gage manufacturers, has offered a standardization program that has helped both the user and the manufacturer of gages. All types of gages have been improved in design and they now will check work more accurately and rapidly. In addition, the



Pratt and Whitney Co.

FIGURE 7(b). Continuous-type electrolimit gage gaging sheet steel in continuous mill.

new-type gages are more stable in size and are much more durable.

A modern ring gage⁵ made from solid Carboloy was used to gage 431,979 aluminum alloy spindles and yet showed no measurable wear on the gage. The mouth of the gage was worn slightly but required regrinding back only 0.030 inch from both sides to recondition it as good as new. Former gages made from hardened high-speed steel had to be discarded after measuring 3,000 to 5,000 similar spindles.

⁵ "Engineering News Flashes," *Machinery*, June 1938, p. 674.

Mechanical and electrical comparators are now widely used by industry. The electrolimit gage combines mechanical gaging with an electrical magnification to obtain either external or internal measurements. The principle includes a simple balanced bridge circuit as shown in Figure 7(a). This circuit is so arranged that any magnetic movement of the points on the gage head unbalances any magnetic field of the coils. The resulting unbalance is shown on the micro-



Pratt and Whitney Co.

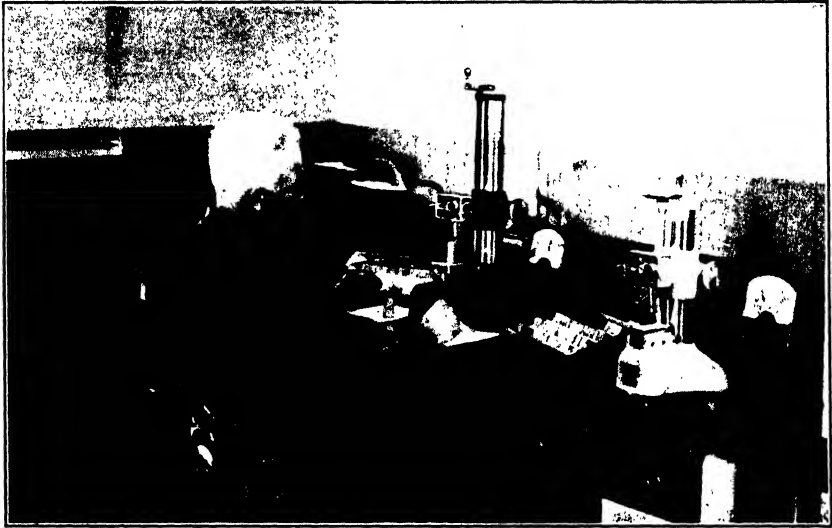
FIGURE 7(c). Central inspection department using electrolimit gages.

ammeter. Adjustments are made on the potentiometer for any given size to bring the microammeter to the proper position.

This type of gage is a rugged instrument which can be used in a number of places. The degree of magnification is easily adjusted over a wide range up to 20,000 to 1, if such a range is necessary. With the high magnifications it is possible to detect differences of a few millionths of an inch.

The indicating meter can be located in any convenient position. This feature allows the use of a continuous-type electrolimit gage, for instance, to gage strip steel in continuous mills. Figure 7(b) illustrates the use of the electrolimit gage for measuring the thickness of the sheet steel from a continuous strip mill. The principle consists of a mechanical gaging contact and electrical magnification. The

gaging rolls control the electric current in such a manner that a microammeter can be used in any remote position for adjustments of the continuous mill. In this particular installation speeds up to 1,500 feet per minute with tolerances of ± 0.00025 inch are being used. Figure 7(c) illustrates a central inspection department for testing pistons. Each operator is using an electrolimit gage for measuring different parts of the piston.



Pratt and Whitney Co.

FIGURE 7(d). Precision-type gages are used to set electrolimit gages.

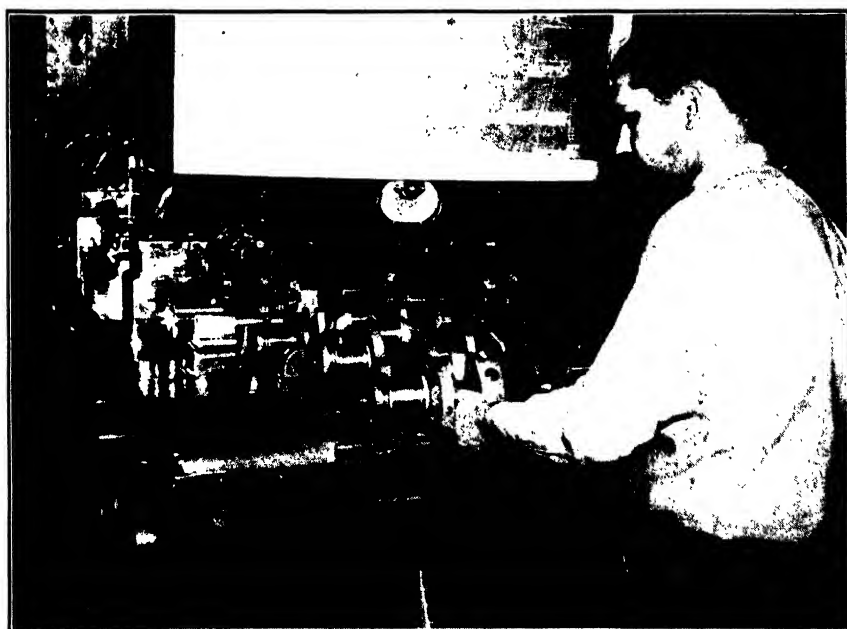
Figure 7(d) illustrates how the gage is set to zero by the use of the precision-type Johansson or Hoke gages. The needle on the microammeter for the desired size is set to the middle of the meter, thus making it possible to show both under- and oversized parts.

Automatic Inspection Machines. The use of automatic inspection machines has increased rapidly in recent years owing to closer tolerances and mass production of certain machines such as electric refrigerators, automobiles, and telephones. Automatic inspection machines also can do better inspection jobs faster and considerably cheaper. The photoelectric cell has made possible a number of such machines which are marvelous to watch. The photocell is very selective in color response and small differences in light received at the cell make it possible to inspect goods for color. This characteristic is used in a number of ingenious ways, such as to sort cigars according to color, to detect cans with missing labels, and to detect tin plate



Ford Motor Co.

FIGURE 8. Automatic machine for inspecting piston pins.

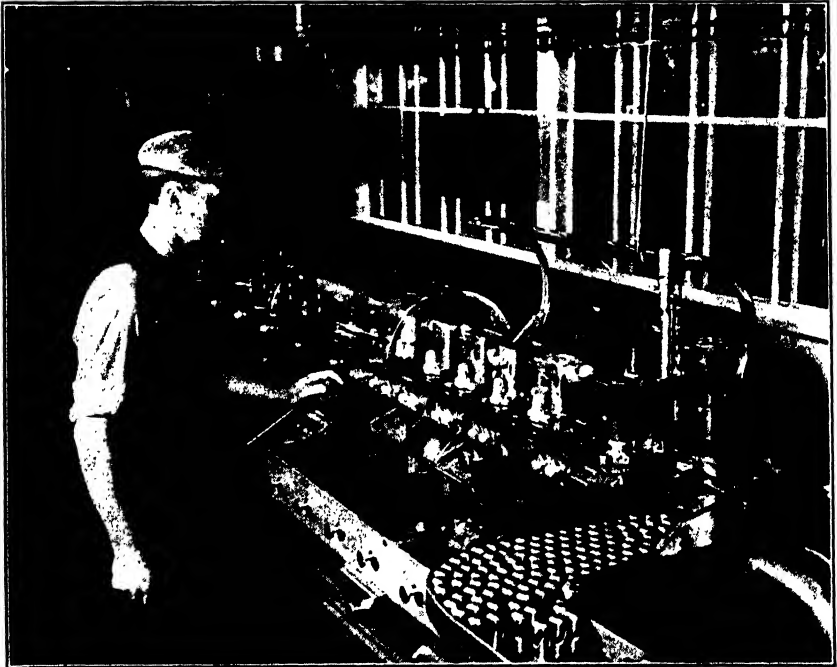


Ford Motor Co.

FIGURE 9. Automatic crankshaft-inspecting machine.

with faulty flow or pin holes in the tin covering. Machines have been developed to control enamel thickness for wire insulation and to reject razor blades which are not keen enough; a host of other inspection jobs may be made automatic by studying the possibilities of using the photoelectric cell.

Machine inspection becomes an economic procedure if the quantity of parts to be inspected, or the number of inspection operations, is



Ford Motor Co.

FIGURE 10. Eleven inspections are made on forty-two valve push rods per minute in this automatic machine.

larger than a certain minimum. Also machines are sometimes used for inspection because they can automatically check to greater accuracies and be more consistent than can hand methods.

Often, machine inspection operations may be combined with certain visual inspection for gross imperfections. The machine generally can act as a pace setter for the visual inspector and thus keep the inspection operation on a steady production rate.

There are a great many kinds of special gaging and inspection machines in actual use. Some of them are completely automatic to the point that they automatically separate the defective parts accord-

ing to the cause of the defect. Others are semiautomatic and require more or less constant attention from an operator.

Figures 8, 9, and 10 illustrate machines for inspecting piston pins, crankshafts, and valve push rods for the Ford Motor Company. The automatic machine in Figure 10 for inspecting push rods performs eleven distinct inspection operations so rapidly that forty-two valve push rods are tested each minute.

This machine, which utilizes photo-electric cells and radio amplification to do its work, inspects valve push rods for hardness, hidden fissures, and accuracy of dimension.

Push rods feed through a narrow slot into one end of the testing machine and are carried upright through two inspections, then are turned 90 deg. to a horizontal position for remaining operations. The push rods are checked for hardness first. An automatic scleroscope works in connection with an "electric eye." A diamond-tipped weight drops on the push rod. If the hardness is correct, the weight rebounds to a predetermined height, intercepts a light beam and the electric eye actuates a mechanism that passes the push rod. Push rods that are not hard enough are rejected and thrown aside.

A hammer strikes the side of the push rod in the second operation. By "listening" to the pitch and duration of the resulting sound, the machine determines instantly whether the push rod structure is without defect. A hidden fissure will curtail the period of sound vibration. A microphone and amplifier are part of the inspection mechanism at this test station.

Nine other inspection operations follow to ascertain accuracy of manufacture. The first is for squareness of the bottom face of the push rod. The allowable tolerance here is 0.001 in. Next the part is measured for roundness, with variation held within 0.00003 in. Squareness of the top is gaged to within 0.00005 in. Automatic fingers then enter the slots in the sides of the push rod to check for minimum wall thickness. Two steps gage the diameter, first at the center and then at both ends, within limits of 0.00005 in.

In the final three sections the parts are measured for length and sorted automatically into seven groups, with only 0.001 in. variation between groups. The seven groups are classified and stacked in boxes as follows:

- (1) Undersize push rods below allowable limit and scrapped.
- (2) Under standard size 0.002 in.
- (3) Under standard size 0.001 in.
- (4) Standard or mean length.
- (5) Over standard 0.001 in.

- (6) Over standard 0.002 in.
- (7) Over allowable limit and reground.⁶

X Ray and Radon Gas. The X-ray machine and radon gas (given off by radium) can detect internal flaws which cannot be easily found by other means. Miles of welded seams were 100 per cent inspected by X rays in the various large pipes constructed for the Grand Coulee Dam. Flaws in castings and forgings may be easily seen by the fluoroscope or they may be photographed. Foreign bodies such as nut shells, cherry seeds, or stones can be seen in fancy chocolate candy even after it is packed, if necessary. Here again the ingenuity of the engineer is about the only limit for this type of inspection.

Radon gas, although not common in many places, has been used in the Foundry Control laboratory at the University of Minnesota for photographing flaws in castings up to 6 inches thick. The photographs are sharper and do not require as long an exposure as the laboratory's 280,000-volt 5-milliamperere tube requires for the same picture.

Stroboscopic Inspection. The stroboscope and its various related devices have made it possible to inspect and study many mechanisms and phenomena in motion which have never before been seen by the human eye. The vibrations of the blades on an electric fan can be studied and inspected to give information for the correction of the vibration. Newer and more intense lights operating on the stroboscope principle have been devised to photograph events which have never before been seen. It is possible to see and photograph the action of the valve springs in a high-speed automobile engine. The springs had to be redesigned to correct the trouble disclosed by the stroboscope. Engineers again can utilize these principles to devise new and better inspection devices for dynamic conditions.

ECONOMICS OF INSPECTION

The engineer can never escape the problems involved in comparative costs between two or more alternatives. Throughout the design, production, and sales of most products, it is necessary to consider these alternatives and their associated costs per unit for the contemplated demand. Inspection techniques in the production department are also subject to the same analysis. A product or part may be inspected in any one of several ways and the end result will usually be satisfactory if the chosen inspection method is sound. The cost

⁶ *American Machinist*, Vol. 81, No. 2, p. 833.

per unit of goods inspected by a special composite gage, where several dimensions are measured at once, should be compared to unit inspection costs of the same part when measured by ordinary single gages. Generally the special gages are of no value when the part is abandoned or changed. Consequently, the entire cost of the gage must be absorbed over the predicted demand and this gage cost divided over short runs may be excessive per unit as compared to simpler methods of inspection.

Automatic machine methods of inspection should be subjected to the same analysis for economical feasibility as that used in Chapter XV, page 333. Each inspection machine should show a profit on its operation unless some other factor, such as the greater inherent unbiased accuracy which can be built into a machine, is more of an asset than slight cost differences.

How Much to Inspect. Another important economic factor is the determination of the percentage of the product to be inspected. The inspection department is responsible for the quality of the material passed and therefore should determine the amount of inspection to be applied. If inspection is carried too far, it may become a financial handicap to the product. The determination of the economic point in the percentage of the product to be inspected depends on a balance between the loss sustained by the occasional imperfect part which cannot be used, and the additional expense of increased inspection which would discover these variations.

If an inspection technique used on a certain class of goods costs 80 cents per 100 pounds of product and results in 94 per cent good product, the cost of a better technique to insure 98 per cent might cost \$2. That is, a gain of 4 per cent in good product would cost \$1.20. If the loss entailed by trying to use the extra 4 per cent of defective material were less than \$1.20, the extra inspection would not be economical.

Figure 11⁷ shows a generalized curve to show the relationships between increments of extra inspection cost and the resulting increment of increased product value. It may be taken as axiomatic that, since perfection is impossible in its absolute sense, the cost of trying to obtain an unobtainable perfection would be infinite. Thus the curve for the cost of quality would finally tend to become asymptotic to the perfect quality line. The cost curve would fall rapidly from this high point as the quality goes lower and lower until a point is reached

⁷ Adopted from "Standard Quality," G. O. Edwards, *Bell Telephone Quarterly*, Vol. 7, No. 4.

where the quality of the materials and workmanship is so low that the part can barely be processed. The cost curve at this minimum quality would tend to become parallel to some minimum cost value.

The factory value of a part for most products is determined by the minimum cost of an alternative part which is equally satisfactory. In a utilitarian article, such as a can opener, few people will pay for the cost involved to form mill the various parts when stampings are

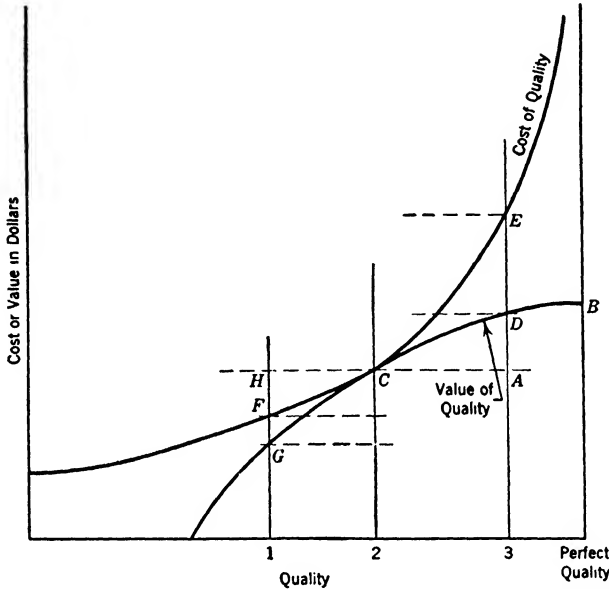


FIGURE 11. Cost of quality as compared with value of quality.

just as good. Consequently, the value of the stampings fixes the value of the part for practical purposes and fixes an upper limit for the value of those parts which can be made by stampings. Therefore, after a period of time the factory cost and value of individual parts tend to become the same.

This conception of value is shown in the "value of quality" curve in Figure 11. Since the cost of coming close to perfect quality is so high, the value must be considerably below the cost at this point. Point B would then represent the value of a perfect part if such a part could be produced. As the quality is reduced towards the left in Figure 11, the value and cost of the part approach each other until a common point is reached at C. Factory values and costs, in some instances, may have several closely spaced points on the curves which are common, but for this discussion these are close enough to be con-

sidered one point. The point C on quality line 2 is the economic quality. If some other quality, say that represented by line 1, is used, the reduction in quality HG is more than the corresponding reduction in cost IIF . That is, quality to the left of point C falls off rapidly to the point where the part is worthless, but the cost of the raw material and some labor still remains. Thus it is advantageous to move the quality line farther to the right.

On the other hand the additional cost of obtaining the quality at line 3, represented by AE , is considerably greater than the increased value of this quality AD . In some instances, it is logical for the quality to be either above or below the economic point on line 2, but more generally the selected quality would be slightly to the right of line 2.

Mathematical Approach to Inspection Problems. The problem of inspection, from a modern viewpoint, is to find how much the quality of a product may vary even if the known and controllable variables are controlled.⁸ In other words how much will the quality vary if only the uncontrollable chance events are left to exert their influence? The statistical method is being applied to aid in the solution of such inspection problems by some of the most progressive companies. The percentage of product to be inspected in each case, along with the probable loss which may occur owing to passing some defective material, can be studied by means of statistics and the laws of probability and chance.

Sampling Procedures. Inspection by sampling procedures⁹ is a means of reducing inspection costs if proper techniques are used. To be able to predict accurately the results from samples, they must be selected and manufactured under controlled conditions. To find and assign the controllable factors which influence quality is a most important part of this problem. All other uncontrollable factors will tend to act on the quality in chance fashion and the defective work, caused by such chance factors, remains to be found by the inspection system.

If, for example, the milled screw slots in a large order of screws were found to be too narrow, the inspection department could catch this by a sampling procedure. But a study would probably show that only two factors could affect the slot width and both of these factors are controllable. If the saw did not run true, the slot would

⁸ "Economic Quality Control of Manufactured Product," W. A. Shewhart, *Bell System Technical Journal*, Vol. 9.

⁹ *Economic Control of Quality of Manufactured Product*, W. A. Shewhart, Chapters 24 and 25, D. Van Nostrand Company, 1931.

probably be too wide. This could be found when the first few pieces were run over the new setup. The slot could become too narrow only by the saw wearing thinner at the cutting edges. The obvious inspection technique was not by measuring occasional samples of the screws, but by occasional inspection of the saw on the machine. On the other hand, if it is possible to assume the rather impossible fact that internal stresses in the metal of cold-headed screws were sufficient after slotting to narrow occasionally the screwdriver slot, the control of this factor may be quite difficult. A random sampling method would be necessary to catch such faulty screw slots because they would be caused by presumably uncontrollable and unassignable causes.

Certain precautions should be observed when the sampling procedure is used. The samples should be selected at random at different times as the operation continues over the entire lot. The most important samples of a lot are the first parts made when the setup is completed and the last pieces made before the setup is torn down. If the machine is functioning properly, a good operator can usually maintain the original quality determined by the correct setup. A sample from the last pieces in the lot will disclose whether deterioration in the original setup has taken place, and an analysis will determine whether anything can be done to control this difficulty.

If some of the selected samples prove to be defective, more samples should be taken and if the parts continue to be defective the entire lot should be rejected or the lot should be 100 per cent inspected if economically feasible.

Many plants, and particularly those using incentive wages for inspectors, have a method of checking inspectors. That is, the accuracy of the inspector's findings are checked by random sampling of work previously passed by an inspector. This second random sampling of an inspector's work is usually done by a second group carefully picked for accuracy.

Dr. W. A. Shewhart of the Bell Telephone Laboratories and others have made special studies of the application of probability theories to inspection problems. These theories and discussions are much too long to include in this volume, but the interested student of inspection problems should study this literature to obtain the mathematical background for more economic inspection techniques.

Inspection work cannot be entirely reduced to an exact science, but scientific analysis can do much to improve and to cheapen inspection processes. It would seem obvious to most people that, if quality is very important for a certain product, it could be obtained best by carefully inspecting every part of the product. In practice,

however, this assumption may not be correct where enormous quantities must be inspected. The mere repetition of a tedious, uninteresting inspection task performed over a long period of time may cause the inspector's interest and physical ability to lag sufficiently to cause trouble. Inspection by controlled sampling of the large lot often does a better job because interest is not sacrificed.

ORGANIZATION FOR INSPECTION

A complete inspection organization should include a quality control on everything from raw materials to finished product including the processes used to produce the product. Tools, gages, machines, and the design, development, checking, and maintenance of inspection equipment, and methods are all included in the normal inspection department's responsibility.

The inspection department should operate as an independent unit directly under the production or general manager. Though the inspection and operating departments are usually under one general head, they should work independently, subject to correlation only from the general manager. Only in those plants where quality control is not much of a problem is it safe to have the inspection under the operating foreman or superintendent of the department.

Where quality control is important, the inspection function becomes an important part of the manufacturing process and the head of the inspection division is placed on a par with other major divisions of the factory organization. The executives of the operating division have many opposing forces working on them to get quick delivery, large output at low cost, and yet high earnings for the workman. Added to these, of course, is quality in the product, but foremen are apt to be somewhat removed from quality considerations owing to the other high-gear demands. As quality becomes more important, it becomes more necessary to supervise and control it by a separate organization which reports directly to an executive who can give due weight to quality as well as to costs and production.

PRODUCTION CONTROL AND INSPECTION

Production planning and control are not complete unless the inspection function is included in the plans. Generally this is done by coordinating the inspection division with the dispatch station. This should not be construed to allow the dispatcher or the production con-

trol department to tell the inspectors how to inspect. The control is set up to tell them when to inspect and when to send a copy of their findings to the dispatch office.

In departments where the manufacturing cycle is quite long the inspector often works from the dispatch board assignments just as the machine operators do. He receives a work order with the necessary blueprints, specifications, or inspection instructions which are turned back to the dispatcher with a report of the findings.

If any of the ordered lot is defective, the report shows how much and the reasons the parts are defective. Defective work may sometimes be salvaged and generally the order is held until these salvaging operations are finished. If the quantity in the original manufacturing order is reduced by unreclaimable scrap, the inspector notes this on his report and the quantities should be reduced on the order before it proceeds.

Defective Work. The disposition of defective work should be controlled by the combined efforts of the inspector, foreman, and dispatchers. Some companies have a number of conveniently located red skids placed in each department for receiving defective work. The red color on the skid warns any unauthorized person to avoid using or tampering with any of the parts placed on the skid. Defective material is generally placed in one of two classifications, that which may be reclaimed and that which is entirely lost and must never be used again for its original purpose.

Defective material is found sometimes in other places in addition to the inspection floor. Sometimes where good inspection methods are not used or where the inspection itself is faulty, the defective parts may be found in the stockrooms or on the assembly floor. Regardless of where the defective material is found or where it is finally delivered, if it can be reclaimed the costs involved in reclaiming should be accounted for. One of the foreman's duties under the modern production control (see pages 545-548) is to issue spoilage reports to show involved cost, reason for the scrap, and the person responsible, if any. If the spoiled parts can be reworked, the foreman should decide the operations necessary to reclaim the parts and then turn the report over to the dispatcher, who handles it like any other manufacturing order.

When standard costs are used, it is desirable to issue a scrap report (see Figure 2, Chapter XVI) which accounts for the value of the scrap so that it may be deducted from the inventory. In addition, a method is provided for controlling excess scrap since the cause for the scrap is known, and possible remedial measures may be suggested.

After the parts have been repaired they join the original order which has been held up at the inspection station pending action of the foreman, the shop, and the dispatcher.

The routine of returning stock for reclamation is the same whether it comes from stock or from assembly floors except for the accounting function which is necessary to show where the defective stock came from and where it is going. If these two places are the same, only the parts which are unreclaimed are deducted from the total number of parts sent to be repaired.

The advantages of modern inspection techniques along with production control to schedule the inspection functions allow a quick turnover of defective materials which prevents work being held up or side-tracked while decisions are pending. The foreman and operator are held responsible for quality; the inspection department is held for quality control methods and finding defective material; and the production control division is responsible for quickly scheduling the reclaimable spoiled material through the shop. Responsibility is clear and carelessness is reduced because the burden of repair correction and responsibility fall directly on the foreman and workman at fault.

PROBLEMS AND QUESTIONS

1. What does the term "best quality" mean to you when you buy a suit of clothes?
2. What tolerances are allowed in your community for a pound loaf of bread as sold from the grocer's shelves?
3. What tolerance is allowed in the ball diameter for high-grade ball bearings?
4. How are these tolerances maintained in Questions 2 and 3?
5. How can machinability affect quality?
6. Explain why you think the need for inspection is increasing or decreasing.
7. How far can inspection go toward creating quality?
8. When are quality and quantity opposed to each other in manufacturing operations?
9. Should inspectors use judgment in rejecting products?
10. What should the responsibilities of an inspection department be for a quality product which is made in a modern plant?
11. What is meant by preventive inspection? How can it reduce production costs?
12. Are material specifications becoming simpler or more complex? How do you explain your answer?
13. What are the advantages of resident inspectors in a vendor's plant?

14. Process inspection may be quite expensive. Why not inspect only the final product for standard performance to avoid this?
15. Name five original process inspections and describe their techniques.
16. Discuss surface-finish meters and their methods of operation.
17. Can machine operators be expected to measure accurately enough to check their work on the machines? How would you provide for it?
18. Do you think inspection instructions should be written by the planning department?
19. When are the inspection department's findings used for other purposes than determining quality of the product?
20. What are the advantages of centralized inspection?
21. What possible extra costs are involved in a decentralized inspection setup?
22. Discuss the principle and the operating characteristics of the electrolimit gage.
23. When are inspection machines advisable?
24. Name and discuss five uses for X ray in inspection jobs.
25. How important are inspection costs in a plant making mechanized office and store equipment?
26. Can inspection be carried too far? What happens?
27. What effect do the uncontrollable production factors have on inspection techniques?
28. Can inspection costs be brought down by the use of assignable causes?
29. What precautions must be observed in sampling procedures for inspection purposes?
30. When should the inspection department be under the department superintendent?
31. What should the relationship be between the production control and inspection departments?
32. Discuss a plan of fixing responsibility and disposing of defective work in a mass production shop.

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Chapters XIV through XVI discuss functions closely associated with production control.

CHAPTER XIV

PLANT CAPACITY, MAINTENANCE, AND REPAIR

Three concepts of plant capacity will be discussed in this chapter. The first will deal with the cost per unit of capacity. The second is concerned with finding the maximum productive capacity of the various production centers. The third concept deals with the maintenance of the ability to produce at or near the maximum capacity.

COST OF UNIT CAPACITY

Large units of certain types of machinery or equipment usually are more efficient and also cost less per unit of capacity. Electric motors, foundry sand mullers, bread dough mixers, butter churns, and many other pieces of equipment can be used as examples of this tendency.

TABLE 1

LIST PRICES FOR GENERAL-PURPOSE SQUIRREL-CAGE INDUCTION
CONSTANT-SPEED MOTORS

1800 Rpm, 110-440 V, 60 Cycles, 3 Phase

Horsepower	Unit Price	Price per Horsepower
$\frac{1}{6}$	\$16.85	\$101.10
$\frac{1}{4}$	17.20	68.80
$\frac{1}{2}$	26.95	53.90
1	37.00	37.00
2	52.00	26.00
5	71.00	14.20
10	117.00	11.70
20	165.00	8.25
50	382.00	7.64
100	666.00	6.66
200	1,175.00	5.88

The cost of electric motors per horsepower decreases very sharply as the horsepower increases. The list prices of standard three-phase motors from $\frac{1}{6}$ to 200 horsepower, are given in Table 1. The curve in Figure 1 is a generalized one which shows the general trend of cost per unit of capacity as compared to capacity rating for many types

of standard equipment. The table of prices shows that a 20-horsepower motor for driving a group of machines would cost \$8.25 per horsepower. If the group consisted of ten machines, and each of them at some point in the process demanded, say, 5 horsepower for a short time, the 20-horsepower motor could probably drive them satisfactorily. The peak demand for power at each of the ten machines would seldom come at the same time, thus allowing the average demand, say of about 2 horsepower, to be easily delivered.

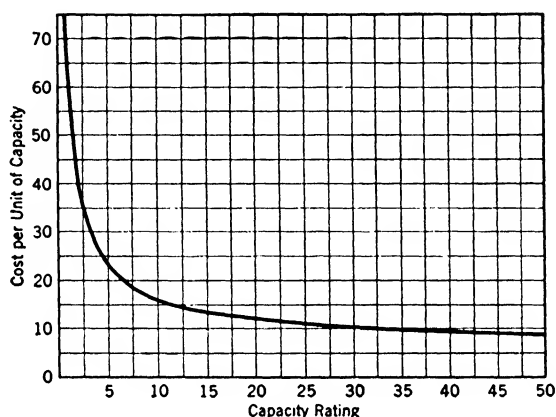


FIGURE 1. Generalized capacity-cost chart.

On the other hand, a 5-horsepower motor would probably be necessary if each machine had its own motor. Moreover, ten motors of this size would be necessary to drive the ten machines. A comparison of the costs to purchase enough capacity to deliver the required power is as follows:

<i>Unit Drive</i>		<i>Group Drive</i>	
Ten 5-hp motors	\$710.00	One 20-hp motor	\$165.00

Some industrial power contracts have a portion of the charge for current based on the connected load. The connected load with the individual motors would be two and one-half times as much as with the group-drive motor. In addition, the 20-horsepower motor at its usual full load is more efficient than the 5-horsepower motor, especially when the smaller motor is coasting along at about half load. Thus, assuming the same current charge for both methods to drive the entire load, the individual method costs more to operate and about four times as much to install over the group drive. There are other cost considerations, of course, such as relative friction losses, belting

costs, and breakdown costs, but they are apt to be less important than the original and operating costs of the capacity to drive these ten machines.

Purchasing Machine Capacity When Load Varies. Some plants have a variable demand for some material or part. If the products can be made in machines or equipment of different productive capacities, it may be well to consider the best-sized unit or combination of units to install. For instance, a foundry might pour enough iron during each four-month period of the year to require, respectively, one 72-inch cupola for the first period, one 48-inch cupola for the second period, and a 36-inch cupola that could furnish enough iron for the lowest period of the year. It obviously would be uneconomical to buy a 72-inch cupola. The problem requires a careful balancing of all costs of operation for each of the combinations of different-sized cupolas necessary to provide the capacity for each period.

It is easy to visualize the following example¹ where water-pumping capacity is to be installed to satisfy a load that varies from 400 to 1,600 gallons per minute. A survey showed that 1,600 gallons per minute were needed for 500 hours per year; 1,200 gallons per minute for 500 hours per year; 800 gallons per minute for 1,000 hours; and 400 gallons per minute for 5,000 hours per year. The remainder of the year no water was needed. The water was pumped against a head of 50 feet in all cases. Electrical energy costs 2 cents per kilowatt-hour. Three likely combinations suggest themselves for study.

1. Purchase a pump big enough to handle the maximum load of 1,600 gallons per minute. The installed price is \$2,000 for pump and motor, complete with all piping, ready to run. The efficiency of the equipment varies with the load as follows:

	<i>Pump Efficiency</i>	<i>Motor Efficiency</i>
1,600 gallons per minute	80 per cent	90 per cent
1,200 " " "	75 " "	90 " "
800 " " "	65 " "	87 " "
400 " " "	42 " "	81 " "

2. The second combination would involve the purchase of two pumps of 800 gallons per minute capacity. Each would cost \$1,450 ready to run. Efficiency would be as follows:

	<i>Pump Efficiency</i>	<i>Motor Efficiency</i>
800 gallons per minute	76 per cent	89 per cent
600 " " "	71 " "	89 " "
400 " " "	60 " "	86 " "

¹ *Principles of Engineering Economy*, E. L. Grant, Ronald Press, 1938, p. 132.

3. The third combination would involve the purchase of four pumps of 400 gallons per minute capacity. Each unit would cost \$1,100. In any of the required loads any unit used would run at full load with the unit's maximum efficiency.

	<i>Pump Efficiency</i>	<i>Motor Efficiency</i>
400 gallons per minute	68 per cent	87 per cent

The three plans should be compared by an analysis of the costs involved in operating each combination. The charges for floor space, depreciation, interest, insurance, taxes, maintenance, and electrical energy should be calculated for each method. It is assumed that, since this type of equipment is not likely to fail suddenly, the necessary maintenance is done during the time no water is required. Consequently, it is not necessary to have a standby pump if the largest one is the cheapest to operate.

The kilowatt demand of each motor is approximated by the formula

$$\text{Kilowatts} = \frac{\text{gallons per minute} \times \text{head}}{5,310 \times \text{pump efficiency} \times \text{motor efficiency}}$$

where efficiency is expressed as decimals for the various capacities.

In each case the combination of loads which consumed the lowest amount of energy was used.

TABLE 2
COST OF VARIOUS FACTORS PERTINENT TO INSTALLING CAPACITY
TO PUMP VARIABLE QUANTITIES OF WATER

Pumping Capacity	One 1,600 G.P.M. Pump	Two 800 G.P.M. Pumps	Four 400 G.P.M. Pumps
1,600 gallons per minute; kilowatts from equation	20.9	22.3	25.5
1,200 " " " " " " " "	16.7	17.9	19.1
800 " " " " " " " "	13.3	11.2	12.8
400 " " " " " " " "	11.1	7.3	6.4
1,600 gallons per minute kilowatts × hours used per year	10,450	11,150	12,750
1,200 " " " " " " " "	8,350	8,950	9,550
800 " " " " " " " "	13,300	11,200	12,800
400 " " " " " " " "	55,500	36,500	32,000
Total kilowatt-hours used per year	87,600	67,800	67,100
At \$0.02 total electric energy charge per year	\$ 1,752.00	\$ 1,356.00	\$ 1,342.00
Maintenance per year @ \$10.00 per pump	10.00	20.00	40.00
Depreciation, insurance, taxes and interest 18%	360.00	522.00	792.00
TOTAL COST	\$ 2,122.00	\$ 1,898.00	\$ 2,174.00

The installation of two pumps of 800 gallons per minute capacity is the most economical when the sum of the fixed and variable costs is considered.

Possible Extra Cost of Using Only One Machine. The above method of calculation can be applied to a large number of problems involving minimum cost of productive capacity. There is one factor, however, which has not been considered in this calculation. If the minimum cost of productive capacity shows that only one machine is needed, many managers will hesitate to place entire confidence in this one piece of equipment. Conservative management often prefers to pay a little more than the minimum rate for the productive capacity to insure at least a partial flow of goods if one of the machines is down for repairs. For this reason many plants use several machines to produce a part when actually there are available more highly productive machines which can manufacture the part cheaper with one super-machine.

Usually this kind of problem can best be solved by analyzing the cost incurred if the single best machine broke down, say for two hours or two days. Such an analysis may show that little or no extra cost would be involved because few other operations were dependent on a continuous flow of material from the broken-down machine. However, it is possible for the breakdown of a single machine to stop an entire department or even a plant if inventory control has reduced the process inventory to a minimum. Here an analysis of the cost of carrying the needed bank to avert the hampering of dependent operations must be balanced against the savings made by using the one machine which produced the parts cheaper.

MAXIMUM PRODUCTIVE CAPACITY

The daily load factor in the ordinary manufacturing plant cannot be considered the same as in a public utility plant. Public utilities have a high percentage of fixed cost which goes on whether the plant runs or not. The production of current is usually a heat process which cannot be shut down without extra cost. It is preferable to have a high load factor twenty-four hours of the day so that the fixed cost can be spread over as many kilowatthours as possible. This type of load is difficult to get, however, for the average utility plant.

On the other hand, manufacturing plants can operate twenty-four hours per day and spread their plant overhead over several times as much product; or, to approach it from another angle, many factories could manufacture their present volume with less than half the pres-

ent overhead charge for plant and equipment, if the plant were run twenty-four hours per day. Most often, however, the reduced labor output in the night shifts, the increased cost of night labor per hour, and the difficulty of maintaining adequate supervision prevent the adoption of this apparently simple plan. Only continuous-process industries, where large amounts of heat energy are needed, operate their plants twenty-four hours per day as a regular procedure. They must be run continuously to operate at all.

An increased load factor is desirable if it reduces unit cost, but this must be known before any generalizations can be made. Manufacturing plants have a different arrangement of cost factors than do public utilities, and comparisons between them should be carefully considered. It has been said that idle capacity never pays dividends, but it should be known whether this "idle time" is part of a 40- or a 168-hour week before the cost balance can be made.

Some of the minor factors of a manufacturing plant must run at a lower load concentration in order to keep the major factors of production at a high load concentration. Tool cribs, crane service, a maintenance division, boiler-feed water pumps, and many other similar devices or services are necessary in most industries. These devices and services are not producers of revenue in the ordinary sense and yet they must be provided in sufficiently large quantities to prevent retardation of the major factors of production. One crane may be considered ample for the average amount of service required, but if expensive machines and mechanics are held up too often while waiting for crane service, additional cranes should be considered.

Plant Bottlenecks. The modern manufacturer is interested in using his machinery to the limit of its production capacity. A producer of a widely sold breakfast cereal was getting 45 packages per minute from each of several production lines. Each line consisted of a series of filling and packaging machines, which operated perfectly together. However, a study of the productive possibilities of each machine showed that the filling operation was the bottleneck of the entire line. These machines used two filling stations for each box. The box hesitated long enough at the first station to allow a large stream of cereal to run into the container until the combined weight of the box and cereal tripped the mechanism to shut off the stream. The box then moved to the second station. The stream of cereal at the second station was much smaller. Because of the small amount of cereal remaining to be weighed at the second station, the small stream allowed better control of the final weight. Though the coarse and fine filling stations for each box gave greater accuracy for that method,

it was too slow. A new weighing and filling machine which weighs only the material is now used. The cereal is weighed in a series of similar hampers and dumped quickly into the boxes as they hesitate momentarily under the funnels. The new filling machines produce 72 boxes per minute, and the other machinery on each line was speeded up to wrap, label, and place the cartons in shipping cases. Thus, when a serious study was made, about 80 per cent of the equipment in each line was found to be operating at only 62½ per cent of its capacity as measured today. In other words, with a time saving of 37½ per cent, the plant produced 60 per cent more product on each line by purchasing one new machine for each line. For convenience, Table 3 shows the relation between saving in time and increase in production.

TABLE 3

TIME SAVED Per Cent	PRODUCTION INCREASE Per Cent
10	11
20	25
30	43
40	66
50	100
60	150
70	233
80	400
90	900

Machines at Full Capacity Reduce Labor and Overhead Costs. Machines should be run at the full capacity of their tools, materials, mechanisms, or motors, depending on which one is loaded first. If a large machine is necessary because the product or part is large, neither the driving motor nor the machine's mechanisms can be fully loaded if only a small tool, such as a T-slot cutter, is used on the operation. However, the T-slot cutter should be run at the speed and feed which is just under its maximum endurance. Machines which are allowed to be run under their economic limits to produce waste man power, overhead, and plant capacity. Machine overhead is generally quite constant up to its maximum production possibilities. Consequently, the more product made per unit of time, the less overhead it is necessary to charge per unit. Moreover, in many cases the machine operator without excess fatigue can continue to keep the machine operating at its peak load. Thus both labor and overhead costs are lower per unit of product if the machine is kept fully loaded.

In some industries, obsolescence is feared more than depreciation. Since obsolescence is difficult to predict, it sometimes may be wise to

run machines beyond their recommended capacities as a matter of policy. Through considerable experience, some plant managers have learned that certain machines are underrated by their manufacturers. Even though the machine's guarantee may be made void and the machine's life shortened somewhat by increasing the speed, the increased capacity may be more economical. Such machines will earn greater profits per year and are more likely to escape obsolescence. If given adequate lubrication and maintenance and no abuse, such as hammering, dirt in bearings, or heavy articles dropped on finished surfaces, many machines will continue to produce good products at higher than normal rates long enough to pay for themselves in a shorter time.

The present policies of the Bureau of Internal Revenue tend to discourage this practice by insistence on depreciation over a maximum life. However, several articles² have been published recently which stress the need for more liberal depreciation policies to encourage industry to keep their plants modern with the best machines they can use economically.

Increasing Normal Capacity of Machines by Alteration. Production executives should analyze mathematically and experimentally all types of machines to determine the maximum capacity. Machine tool and equipment manufacturers try to produce a balanced design on their machines. Sometimes, however, the user of these machines finds that the strength of certain more or less minor parts limits the capacity of the entire machine. For instance, by substituting a stronger feed rack, made the same size as the original but from stronger steel, it is sometimes possible to take heavier cuts on engine lathes. Methods have been devised to calculate chip pressures and horsepower requirements for certain chip areas, but this procedure has so many uncontrolled variables and so many possibilities of error that the experimental method is often quicker and more reliable. Metal- and wood-working machines often have limited production possibilities because of surface finish requirements. If the machines are rigid enough to prevent chatter, broad-nose tools can produce smooth surfaces with faster feeds for lathes or planing types of metal-working tools. More rigid fixtures, arbors, and better designed cutters can increase capacity of milling machines. Faster motors directly connected to wood-working machinery will allow faster feeds without impairing the surface finish. If the machines are taking both a roughing and finishing

² "Should the Tax Laws Permit Speeding Up Depreciation?" *Modern Industry*, Volume 13, Number 3; "Needed: A Sensible Depreciation Policy," *American Machinist*, Volume 90, Number 9.

cut, the roughing feed can be increased to just under the point where the power is insufficient to turn the machine up to speed. If, in the meantime, the machine does not chatter or the work itself is not distorted by the heavy cutting, the ability of the machine to deliver power to the tool is the deciding factor. A critical inspection trip through most plants will disclose many machines loafing along with part of a load when more could be easily carried.

In certain classes of machines such as looms, printing presses, and packaging machinery, there are a number of oscillating mechanisms which resist high speed owing to their inertia forces. Higher than normal speeds tend to make this type of machine vibrate excessively with damage to certain parts. Dynamic balancing and occasional redesign of a bad part will enable individual machines to produce more, thus increasing plant capacity. Redesign of a reciprocating part which is causing excessive vibration can often be expedited by substituting another material for the original. If steel is substituted for cast iron in a rapidly moving part, the reduction in weight to produce the same strength will reduce the stresses and the vibration in the part. For the same reason such parts have been redesigned for aluminum or magnesium alloys.

Many plants baby their machines in an effort to make them last as long as possible. Actually they should be given good maintenance and the best lubrication it is possible to get, but they should be driven at full speed and capacity for maximum production during the time they are used.

Determination of Optimum Capacity. Each item of equipment in any plant has a certain maximum productive capacity under present conditions. A foundry cupola can melt a certain quantity of iron at a definite temperature. This capacity is based on the coke-iron ratio, the pressure, the quantity of air blown through the tuyères, and other lesser factors. If any of these factors is changed very much from the theoretical ideal, the production per hour is materially changed.

Definition of Optimum Capacity. Other pieces of equipment—butter churns, cement-mixing machines, or engine lathes—are capable of producing an optimum amount of goods at least cost per unit. Optimum capacity may be defined as the output which can be produced at the lowest over-all unit cost. This optimum should be known and posted on a card for each machine. In times of great demand, most machines and equipment can be forced beyond this optimum rate of production, but the unit cost may also be higher. The law of diminishing returns should begin to operate if the optimum rate is ex-

TABLE 4
CAPACITY OF A 24-INCH DRILL PRESS *

Sliding-Head Drill Press
Actual swing: $24\frac{1}{2}$ inches
Diameter of table: $21\frac{1}{2}$ inches
Vertical traverse of spindle: $10\frac{1}{2}$ inches

Machine Number—D-73
Maximum distance, spindle to table: $35\frac{1}{2}$ inches
Maximum distance, spindle to base: $52\frac{1}{2}$ inches
Traverse of table on column: 13 inches

For Cast Iron

d	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$	2
f	0.012	0.016	0.020	0.025	0.025	0.025	0.030	0.025	0.025	0.020	0.020	0.020	0.016
n	640	450	320	225	160	160	160	112	112	112	112	80	80
nf	7.7	7.2	6.4	5.6	5.6	4.0	4.0	2.8	2.8	2.2	2.2	1.6	1.3
h	0.07	0.11	0.14	0.18	0.25	0.29	0.32	0.36	0.40	0.43	0.47	0.50	0.58

For Steel

d	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$	2
f	0.008	0.012	0.014	0.016	0.012	0.010	0.008	0.008	0.007	0.006	0.006	0.006	0.005
n	640	450	450	320	225	225	160	160	160	160	112	112	112
nf	5.1	5.4	6.3	5.1	2.7	2.3	1.3	1.3	1.1	0.96	0.67	0.67	0.56

d = drill diameter in inches
 n = spindle speed in rpm.
 f = spindle feed in inches per spindle revolution
 nf = spindle feed in inches per minute
 h = cone height of drill in inches

* *Cost and Production Handbook*, L. P. Alford, Ronald Press, 1934, Section 15, p. 801.

ceeded. If the unit cost does not increase at higher production rates, the optimum rate has not yet been reached.

More generally, however, the usual production rate is less than the optimum because many plants do not know the optimum rate. Method analysis through motion and time study techniques is one of the best ways to find the practical capacity of a machine.

Use of Optimum Capacity to Estimate Job Work. For estimating work in a job shop, it is desirable to have a complete analysis of the productive capacity of the various machines in the shop. This analysis can be placed on a card with a unique number for each machine. Table 4 shows such an analysis for a 24-inch drill press. It lists the constants of the machine which determine the maximum size of the piece it can work on. In addition, the drill sizes, feeds, speeds, and cone height of drills are also listed to allow estimates of drilling times to be quickly made by means of the formula.

Time required to drill through any thickness of cast iron or steel

$$T = \frac{L + h}{nf}$$

where T = time in minutes.

L = thickness of metal in inches.

h = cone height of drill in inches.

n = speed of drill in revolutions per minute.

f = feed of drill in inches per revolution.

Table 4 is for illustrative purposes only. The capacity of any machine is dependent on the power available from the motor or line shaft, the type of work to be machined, and the coolant used. This is why each plant should study its own machine capacities and not depend on published material *unless it is known* that the working conditions are identical.

As new developments in cutting tool materials, coolants, and materials which require different processing time become known, the capacity studies should be repeated to bring the cards such as Table 4 up to date. Thus the planner in the production control office is kept informed of the latest production possibilities inherent in the shop machinery.

From specifications on the instruction sheet of the proper speeds, feeds, and other working conditions, the shop knows the standards which were used to set up the schedules. The foreman can check operating conditions with the planned conditions to make his work come out as planned.

Efficient Use of Optimum Capacity. After the ultimate production capacity of a machine has been determined and we are satisfied that everything has been done to make it possible to produce at the optimum rate, it is then a question of how well we use this maximum capacity of a machine or plant. The efficiency of heat-power engines, screw jacks, chain hoists, and similar mechanical devices is comparatively easy to obtain; output and input are fairly definite quantities and the relation output/input is by definition the efficiency of this class of machines. This same kind of efficiency can be obtained for an engine lathe, for instance, by suitable instruments, but the output would be the power available at the cutting tool while the power supplied to the machine would be the input. The difference between these two quantities would be the power absorbed by speed-changing transmission, friction, and various controls and feeding mechanisms. The output (power at tool)/input (power to machine) would be the power available or the efficiency of the machine to use power. This would not be of much value except possibly to show which machines of a class would be less wasteful of power.

A ratio which shows how well we use the optimum productive capacity of the various machines is more useful to the production control division. It can be expressed in several ways: first, *actual results* obtained in a plant as compared to the most productive known results obtained anywhere. This ratio may benefit a manufacturer since it tells how he compares with the best producer in the business. In so far as the best performance in a field can be known, a manufacturer can thus determine how well he is equipped to meet severe competition if and when it comes. The best as a measuring stick seldom remains constant for long; consequently, the standard is a variable one and often hard to obtain. The efficiency of a machine or plant gradually decreases by this scheme and, even if the executives know what is being measured, the diminishing ratio over which they have no control still may have a depressing effect.

A second and more logical method of calculating production efficiency is the ratio of actual production over a period of time, perhaps a day or month, to the optimum production as defined and discussed above. Under this plan it may be possible to operate some machines at production efficiencies of over 100 per cent. Since production at higher than the optimum rate, however, would often cost more per unit produced, production efficiencies of more than 100 per cent would not be economic except under special conditions. Thus production efficiency calculated by this second method uses a constant goal which is altered only by a fundamental change in the method of operation.

An operation can be interrupted by many things such as power failures, stock shortages, labor absences, personal needs of the workmen from time to time, and machine failures. Any of these can delay production, and once production is lost it cannot be regained in that period of time.

A dough divider for a mechanized bread bakery can separate bread dough into pieces of the proper size to make a loaf of bread, but if the dough has a variable density from one batch to another so that considerable adjustment must be made from time to time, light- or heavy-weight lumps must be thrown back into the hopper to be rerun. If insufficient oil is sprayed on these molds or if flour is not evenly spread on the conveyer under the divider, the loaves tend to stick together and two or more lumps are kneaded together in the next machine called a rounder. The dough-divider operator watches for the multiple lumps and returns them to the divider. Such productive losses will increase as the proof-room workmen allow dough of variable density to be delivered to the divider or as the dough-divider operator ceases to watch the machine carefully enough. When everything is working smoothly, the efficiency is about 95 per cent.

In addition, another ratio is obtainable which is valuable as a cost element. In a bakery which produces from 50,000 to 100,000 loaves of bread per day, a very small overweight, say one-half ounce, on each loaf will amount to over 3,000 pounds of dough per day per 100,000 loaves. On the other hand, eagle-eyed city inspectors carefully check at random in the retail stores to catch the short-weight loaves. Between these two alternatives of over and under weight the operator of the dough divider must be constantly testing the weight of the lumps of dough. Weighing and adjusting reduces the machine's productive capacity. Both the percentage of the use of dough and of the machine are important for themselves, but the real efficiency of man and machine is best measured by a combination figure. This percentage is calculated by multiplying the percentage of loaves produced, as compared to machine capacity, by the theoretical percentage of possible pieces made from the dough used. Thus, if the machine produced 95 per cent of the optimum capacity and the man watched his weighing carefully enough to get 97 per cent of the theoretical pieces per quantity of material used, the resulting efficiency of the man and machine is $0.95 \times 0.97 =$ about 92 per cent. If percentage figures of this kind are charted from day to day, the production department knows where the losses have occurred and possibly can correct them.

In some respects, it is not entirely fair to calculate the efficiency of a machine or the operator and machine together over a long period of time. Losses over which the machine or man has no control should not be included in the final calculations. The machine should be charged with any losses caused by necessary repairs, adjustments, tool failures or changes; but failure of power and lack of stock or labor to run the machine is not directly chargeable to it and should not have the effect of reducing the calculated efficiency of the machine.

Factors Which May Affect Plant Efficiency. Carefully determined machine or plant capacities can be materially upset by failure to furnish sufficient and proper tools, auxiliary equipment, or services to maintain the original conditions existing when the optimum production was set. A considerable amount of labor trouble and failure to make schedules can be traced to this lack of maintaining standard working conditions as constant as possible.

The number of machines an operator should tend has a bearing on the capacity of the individual machines in question. Depending on the type of equipment and the product, one man may tend from one up to one hundred or more machines. The economic number of machines per man will vary somewhat with the market for the product. If the plant is behind on orders, maximum production per machine is important and fewer machines per man will cause less interference and therefore more product. On the other hand, if the plant is ahead of orders, interference among the machines and the operator's time are not so important and more machines can be assigned per man.

If an operator can tend six machines as a maximum, the production per machine is a certain amount. This production per machine is reduced to some extent by interference, because the man is not always available when the machines need attention.

The production per machine can be increased owing to less interference by reducing the number to three machines per man, but the cost per unit of product will probably be increased. Thus it is seen that capacity to produce is dependent upon still another factor—the number of machines tended by one man.³

Unbalanced Department Capacities. Plant capacity⁴ apparently should be some function of the various machine capacities. However, in any given plant the capacity of certain departments may limit the production of other departments. Growth of productive facilities in

³ For a more complete discussion and analysis of this problem see F. L. Eidmann's *Economic Control of Engineering and Manufacturing*, McGraw-Hill Book Co., 1931, pp. 250-255.

⁴ *National Association of Cost Accounting Year Book for 1930*, pp. 172-174.

any department sometimes cannot be kept balanced with all other dependent departments. If a new machine is added to a department it may be able to produce considerably more material than some other dependent department could use at that time. If this excess material can be used only by the dependent department, the usable capacity of the first department is only a part of its theoretical capacity. Until sales demand makes it necessary or desirable to increase the capacity of the dependent department, the cost of the unused portion of the first department should be charged to the idle plant account.

Difficulty of Defining Plant Capacity. Thus, it can be seen that the term capacity is not always easy to define. It may have a variety of meanings and each one should be clearly understood. Each machine, department, and plant has a theoretical capacity which is obtainable only if everything runs continuously and perfectly. This efficiency is obviously unobtainable and exists only as a goal to approach. The unavoidable delays for setup, repairs, and all the small shutdowns for the everyday greasing, oiling, waiting for tools, material, and other things which happen to slow down production cause the capacity to be somewhat below the theoretical optimum. One of the functions of production control is to reduce these delays to a minimum, but no one would be naive enough to believe that all delays can be eliminated. The best average performance with the minimum of operating delays could be called the practical daily optimum capacity.

Factors Which Affect Annual Capacity. Over a period of several years, the average annual capacity of a plant or machine is subject to other factors which tend to reduce it below the practical daily optimum. Insufficient sales demand is the most important item of this group, but others, such as floods, fires, strikes, major breakdowns, or other causes, may reduce the average annual capacity somewhat below the practical daily optimum.

To some degree management can exercise a measure of control over this last group of factors tending to reduce the average annual capacity. Low sales volume usually responds to the stimulus of lower prices. The Nunn-Bush Shoe Company and others use this method as a possible way of stimulating production and gross income. (See Chapter XVII.) In certain areas near the Ohio River where floods have been common, some manufacturers have been able to build flood control dikes, dams, and high-capacity pumps to protect their plants. Fire hazards are largely controllable by proper employee and managerial action. Briefly, progressive management can and does foresee and forestall many of the so-called unpredictable major happenings which

tend to reduce the average annual capacity of a plant. Opportunist management is caught flat-footed and production is held up until belated forces are brought to bear upon the immediate cause of the trouble.

EFFECT OF PROPER MAINTENANCE ON PLANT CAPACITY

Maintenance, or the lack of it, is a large factor which decides whether or not any certain capacity of a plant can remain constant. Machinery needs attention periodically or it may quickly lose some or all of its productive possibilities. Proper maintenance, therefore, is essential to the continuous, smooth, efficient operation of any plant.

Relation of Maintenance to Selection of Equipment. Real maintenance begins during the studies which should be made of proposed equipment before its purchase is completed. Similar equipment from different manufacturers may have different performance records. The men who specify the machines for a plant should study the maintenance expense record for each class of machine to be purchased. If other things are equal, the machine which can show satisfactory performance with the least maintenance expense should be the one to purchase. Machinery which is strong, well designed, equipped with good bearings, and well lubricated will reduce the load on the maintenance department.

Organization for Maintenance. The executive in direct charge of maintenance should be selected with great care for his technical skill and organizing ability. An industrial plant needs competent technical advice and aid to keep the complicated machinery of a modern industry running at maximum efficiency day in and day out. Since the maintenance, or, as it is sometimes called, the plant department, often controls all building services such as heating, lighting, cleaning, and all repairs to mechanical and electrical equipment, it has a variety of engineering problems which must be skillfully planned by competent men. The day of the occasional handy man with an oil can and a monkey wrench is about over because he is not competent to repair the complex mechanisms which are found in modern plants.

Maintenance Problem Is Becoming More Important. Year after year has seen the introduction of more and more mechanization to replace hand operations. Machinery, materials handling equipment, and the use of large amounts of power in several forms have been increasing at an accelerated rate during the last decade. The present emphasis placed on the various expenses to *maintain* labor in all types of plants has tended to increase sharply the rate of mechanization. Since not

even the best of the new machines have the inherent ability to repair themselves like those of the biological world, it means the maintenance function is becoming increasingly important. The failure of a conveyer or any important machine can cause a far greater economic loss than formerly because other processes are depending on the equipment which has failed.

Perhaps some time in the dim, distant future we may have large-scale productive operations performed without human labor, but maintenance will always be necessary because repair work cannot be made automatic.

Lubrication Is a Strong Ally of Maintenance. Proper lubrication always reduces the demand for maintenance. Practically everyone understands this simple relationship, but machines continue to fail faster because no one is made responsible for damage caused by lack of oil. If a man is given a reasonable number of machines and pieces of equipment to keep lubricated, he will soon learn his job and what he is responsible for. An oiler's job may seem insignificant, but, if he is given a clear picture of his duties and the extent of his responsibilities, an oiler can derive a great sense of satisfaction from doing his job well.

An editorial in *Factory Management and Maintenance* emphasizes the importance of proper handling of machinery oilers and inspectors as follows:

Several readers have asked for details of the best method of supervising the work of oilers and inspectors. Seemingly there is no one best method, judging by the divergent practices followed in different plants.

In some places the work of the men is closely supervised and checked by the foreman responsible.

Practice of requiring the men to file a daily report in which the work done is described or checked off is followed at other plants.

A third system which is quite widely used is based on the principle of developing personal responsibility. Each oiler or inspector is put in charge of the equipment in a given area, and held responsible for keeping it in shape.

Each of these methods may be the best for the plants in which it is used. Certainly the caliber of the men employed in the maintenance department and plant conditions in general will exert an important influence on the success of any method of supervision and control. If equipment is in poor condition, men can more easily cover up their shortcomings. When machines are hard to get at and there is undue risk of personal injury, it is to be expected that there will be neglect and shirking.

On the other hand, when competent men who are interested in their jobs are given the right working conditions and some incentive to develop personal responsibility and pride of workmanship, supervision practically ceases to be a problem.

Oil Should Not Be Wasted. Many plants use a variety of oils entirely out of proportion to the service demands made on these oils. Surveys should be made to determine which oils or mixture of oils are used on each job and the reasons given by the foreman. Such a survey will usually show a wide variation in the oils used for the same job in different departments. If two or more oils are used for the same job, tests should be made to determine which one is the best for the particular job. One firm found by actual count that eleven cutting oils and fourteen lubricating oils had been used. By careful test and selection of the best oil in each case, it was found necessary to carry only two cutting oils and four lubricating oils. This same firm used eleven barrels of expensive high-speed spindle oil per week before the study. The study showed the high-priced oil was no better and in some places not so good as a lower-priced, general-purpose oil. Consumption of the expensive oil fell from eleven barrels per week to one.

When oil is used in the ordinary way, much of it is wasted. The best evidence of this is the way the oil remains in the fully enclosed sealed spindle bearings—virtually lasting over the life history of the machine. Studies have shown that 90 per cent of the oil used in factory machinery is wasted. Savings can be made by using the correct oil, but more savings can be made by reducing the percentage wasted.

Despite the progress in developing better oils to do the work of several old-fashioned lubricants, there is still need for special-purpose oils in many plants. Keeping the various oils in their proper drums, oil cans, and bearings becomes a major problem unless some system is adopted to aid identification. R. J. MacMullan⁵ advises the use of a color scheme coded to identify the oil and the frequency of application.

Different colors are used to identify the various lubricants. For example, in Figure 2, in the outer circle yellow could indicate a gen-

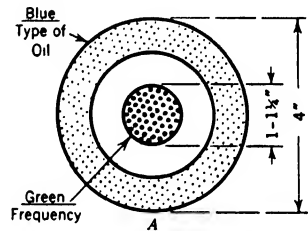


FIGURE 2. Method of marking oil holes to show type of oil and frequency of application.

⁵ "Colors Tell Which Oil, When," R. J. MacMullan, *Factory Management and Maintenance*, February 1939, p. 79.

eral-purpose oil and blue could indicate electric-motor oil. Other colors could be used in the center, or bull's-eye, to specify the period or frequency of application. For example, a red spot could indicate a bearing oil hole which requires lubrication every few hours, and green could indicate monthly application.

After the proper oil has been selected and the frequency of oiling is known, the proper circle and inner dot are placed on each place to be oiled. It is only necessary then to be able to identify easily the various oils at all times, to be sure of good lubrication. If all the oil cans, drums, and other oil containers or storage facilities have a band of color which corresponds to the code, the system is complete and will prove a real aid to intelligent maintenance.

Recording Meters Are an Aid to Maintenance. The ability to discover trouble before it becomes serious is often greatly improved by the use of meters of several kinds. Recording meters for electricity, gas, steam, and liquids not only are useful for allocating costs for these things to various departments, but their charts can tell when something has gone wrong. Most processes will produce graphs with fairly definite patterns. When the periodic examination discloses a peak curve where the usual pattern has indicated a valley or if any other unusual change appears, an investigation should be made to determine the cause. Incipient losses are thus discovered before they become serious.

Recording meters are on the job, automatically disclosing facts of importance which may be overlooked otherwise. They give the management twenty-four-hour supervision and, in effect, they enable the executives to know department costs as well as to practice preventive maintenance.

Classes of Maintenance. There are three general types of maintenance which may be classed as major, minor, and emergency repairs.

The real difference between major and minor repairs lies chiefly in the larger expenditures required for the major work. These expenditures should be estimated and finally approved by several top executives before work is started. Emergency repairs must be handled with good judgment. This type of repair work should not be common if the maintenance division is doing a good job of preventive inspection to discover difficulties before they occur. However, there will always be the pure accident or the sudden unpredictable failure to be taken care of. It is important that proper authority to initiate action be easily available for emergencies.

Economic Analysis of Repair Cost.⁶ As a machine gets older it usually costs more each year to keep the productive capacity and the ability to produce quality work equal to that provided by the machine when it was new. If records of repair and maintenance expenses are kept of one or a group of similar machines, a graph of these expenses with years as abscissas and cost as ordinates shows the form of the cost curve. The curve may have a variety of forms, but in general it can, for practical purposes, be considered to be either a straight line or curve, most likely of parabolic shape. Figure 3 illustrates

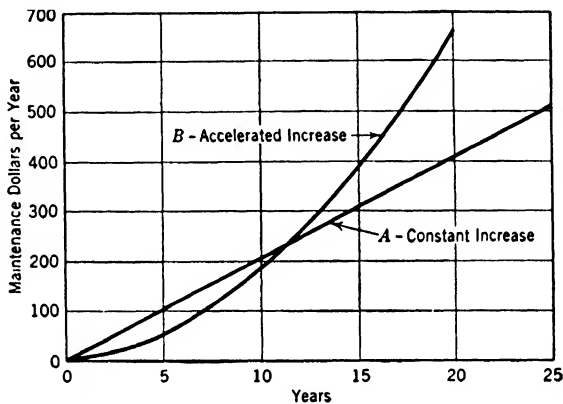


FIGURE 3. Curves show two general patterns of repair cost increase per year.

possible forms these curves may have. The straight line *A* could be parallel to the axis where an equal sum is expended per year or the line could be at an angle to the *x* axis to show that a constant increase is necessary in the sum expended each year. The curve *B* shows a progressively larger increase in the amount needed for repairs each year. It is difficult to think of a machine where less money would be necessary for repairs per year as the machine becomes older, unless the machine is allowed to deteriorate rapidly. There may be some types of equipment requiring no expense for repairs for an initial period of years, but after that period the repair expense could follow any of the suggested curves. The maximum and minimum concept in calculus is useful in developing equations for determining the point beyond justifiable additional repairs. After these equations are developed, they are simple to use and any interested person, whether he knows the calculus or not, can use them to advantage.

⁶ *Economic Control of Engineering and Manufacturing*, F. L. Eidmann, McGraw-Hill Book Co., 1931.

Let N = net cash investment for machine ready to run, when new.

G = total sum of all money expended for repairs and maintenance during X years.

X = number of years machine is economical to keep.

J = annual percentage allowance for interest, taxes, insurance, and depreciation in per cent on net cash investment (N).

Y = average annual cost of repairs.

The solution of this problem is to find the number of years (X) for which the sum of the average annual charges is a minimum. It makes no difference whether the interest, taxes, depreciation, and insurance are calculated on the entire investment or on the average investment over the life of the machine, because they are constants in the differentiated equation. There are other fixed costs, such as general factory overhead, which contribute to the total annual charges, but since constants disappear in differentiation it is enough to illustrate with one set of fixed costs such as NJ . It is also necessary to assume that enough money is spent on a machine to keep its productive capacity constant during the period of X years. Otherwise an added variable cost of lost capacity is introduced.

$$\text{Annual charges } Y = NJ + \frac{N + G}{X} \quad (1)$$

If we assume the straight-line curve for annual repairs,

$$Y = BX \quad (2)$$

And since G = total expenditure for repairs it amounts to the area under the curve for X years. Then for the straight line

$$G = \frac{YX}{2} \quad (3)$$

Substituting the value of Y from (2)

$$G = \frac{BX^2}{2} \quad (4)$$

Substituting the value of G in (1)

$$A = NJ + \frac{N}{X} + \frac{BX}{2} \quad (5)$$

Differentiating

$$\frac{DA}{DX} = \frac{-N}{X^2} + \frac{B}{2} \quad (6)$$

A is a minimum when

$$\frac{DA}{DX} = 0$$

Therefore

$$-\frac{N}{X^2} + \frac{B}{2} = 0 \quad (7)$$

$$X^2 = \frac{2N}{B}$$

$$X = \sqrt{\frac{2N}{B}} \text{ years} \quad (8)$$

In the straight-line form of repair cost, the only factors necessary to consider in solving for X are the original investment and the slope of the curve or annual increase in the cost of repairs.

This problem can also be approached from the total amount of money which can be economically spent on a machine. From (4)

$$G = \frac{BX^2}{2}$$

Substituting value of X from (8)

$$G = \frac{B}{2} \frac{(2N)}{(B)} = N \quad (9)$$

This simple relationship for a straight-line increase in repair cost shows that it is no longer economical to keep a machine after the total cost of repairs exceeds the original first cost of the machine.

An example will show how simple this calculation is. If a machine similar to others already installed in the plant is known to require maintenance at the rate of \$20 per year at the end of the first year, \$40 per year at the end of the second year, \$60 per year at the end of the third year, etc., how many years would it be economical to keep this machine if its original installed cost was \$800? What total could be expended economically for repairs?

$$Y = BX$$

or

$$60 = 3B \quad B = 20$$

Then

$$X = \sqrt{\frac{2N}{B}} = \sqrt{\frac{2 \times 800}{20}} = \sqrt{80} = \text{about 9 years}$$

From $G = N$ (equation 9), a total of \$800 could be expended for repairs.

If, for the moment, we assume that it would be possible for any machine to continue producing by spending the *same* amount each year to maintain its productive capacity, the curve of this type of expenditure would be parallel to the x axis. The equation of this type of curve is $Y = C$. The total area under the curve for repair expense equals CX . Substituting this value for G in (3) and solving as before for X , we get for an answer an infinite number of years. Thus, regardless of how careful we are to select a constant sum which is to be spent each year, we cannot solve the maintenance problem that way. We either spend too little, or too much. Too little expenditure will not maintain the machine in working order and the other is not economical because it spends too much in the first years of the machine's life. Here an absurd assumption should and does give an absurd answer.

If the sum for repairs is increased each year by an ever-larger sum as shown by curve B in Figure 3, the equation can be parabolic in form. The equation for such a curve is $X^2 = 2PY$. The equation for the sum of total repairs, under curve B , is $G = XY/3$. Again using the same technique as before, the equation is developed

$$X = \sqrt[3]{3PN} \quad \text{and} \quad G = \frac{X^3}{6P}$$

Substituting the value of X in G , $G = N/2$ where the curve of repair expenses is a parabola.

Where the repair expense curve is a parabola, the total amount spent for such repairs should not exceed one-half the net investment in the machine when new.

In identical fashion, one can determine the economic limit for repair expense allowance on any machine if he knows the coordinate relationships between the two variables—expense per year and the number of years.

This method of mathematical analysis shows that caution must be exercised to prevent unwise expenditures for maintenance or repairs. Major repairs should be carefully studied and the expense estimated so that no particular machine will have more than its total optimum amount spent for repairs.

Control over Maintenance Expense. Many firms base their equipment maintenance expense on the value of the equipment in the plant. This seems to be a logical method since the value should be a measure of the amount of maintenance needed. However, the age, condition,

hours, and severity of use of the equipment in any given plant will alter the percentage of the value used for the maintenance budget. The plant's past expenses for maintenance can be used as a basis for budgeting action with adjustments to be made after further experience.

Some plants scrutinize each maintenance expenditure over a certain amount. For instance, when repairs are estimated to be under, say, \$50, they are classed as a minor repair and are done in a routine way, and the charge is made against the department. However, amounts over \$50 are classed as major repairs and must have the approval of one or more executives.

Maintenance Tickler System. The modern tendency is toward systematic inspection which is scheduled at the proper frequency to find incipient trouble before failure actually occurs. Breakdowns are not only expensive because of loss of production from the broken machine, but often the operator of the machine must be paid while he waits for the repairs. Moreover, there is loss of profit from the lack of production and that portion of the overhead costs which cannot be recovered while the machine is idle.

An important function of the maintenance division is to reduce losses due to machine breakdowns by anticipating trouble and replacing parts before breakdown occurs. Systematic inspection such as described in the *Cost and Production Handbook*⁷ will prevent most serious trouble and keep production running smoothly. A tickler system as described⁸ tends to spread the maintenance work rather evenly over the year. Inspection schedules are arranged to have about the same number of machines and production centers to be worked on each week by the maintenance division. This tends to make better average use of the mechanics in the repair department.

PROBLEMS AND QUESTIONS FOR DISCUSSION

1. Why do larger units of many types of factory equipment tend to be more efficient?
2. Why does large-capacity equipment tend to cost less per unit of capacity?
3. Is the tendency in Questions 1 and 2 universal? What are the practical limitations?
4. A 50-horsepower motor is needed for a machine-shop line shaft drive. Motors in this size are available in several different qualities. One which costs \$540 has an over-all efficiency of 83 per cent. A better motor which

⁷ *Cost and Production Handbook*, L. P. Alford, Ronald Press, 1934, pp. 759-763.

⁸ *Idem*.

has an over-all efficiency of 87 per cent costs \$595. The better motor has ball bearings in addition to other features which makes it more efficient. If it is important to the solution, the cheaper motor requires lubrication once a week which requires ten minutes' time of a 90-cent-per-hour man. The economic life of both motors is twenty years. Interest, taxes, and insurance is 11 per cent. Which motor is the best purchase if energy costs are 2½ cents per kilowatt-hour? Where does the break-even point occur?

5. Can two or more machines of one type ever be justified if one machine of another type can do the job?

6. Why do not more manufacturing plants build smaller plants and operate them for more than one shift?

7. Can idle plant capacity ever produce dividends?

8. A new machine saved 33 per cent of the old production time. How much was production increased?

9. Is it good policy to operate machines beyond rated capacities?

10. How would you increase the productive capacity of a wheelbarrow, a blanket loom, a drill press, a paper mill, and a wood planer?

11. When is it wise to force a machine beyond its optimum capacity?

12. How would you calculate the production efficiency of a wood planer?

13. Under what conditions should a plant reduce the number of machines which one man operates?

14. Why is plant capacity difficult to calculate?

15. Under what conditions is management responsible for reduced capacity?

16. Can proper repair procedures keep machinery in original condition?

17. Why is maintenance increasing in importance?

18. Devise a plan of insuring good maintenance in a flour mill grinding 3,000 barrels of flour per day.

19. How can waste of lubricating oil be prevented?

20. Can expensive recording meters of various kinds be justified for controlling department expenditures?

21. A machine's original cost is \$2,500. Repair cost over a period of years has tended as follows: \$50, \$125, \$200. How many years should the machine be kept to give minimum expense during its life and how much total should be spent for repairs on the machine?

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CHAPTER XV

MACHINE REPLACEMENT

Machinery and Rate of Production. The rate of production of one plant compared with that of another plant in the same industry is closely related to the difference in productive capacity of their respective machines. However, the extensive use of motion study in one of several plants all using the same type of machinery will usually make the motion-minded plant the most efficient. In a comparative cost study made of three selected woodmills out of twenty-three in the Minneapolis-St. Paul metropolitan area, it was found that, although the mill owners had accused each other of selling below cost, the actual costs of individual operations used in producing the standard mill work for a six-room house varied on the average from four to one to as much as seventeen to one. That is, although each mill had essentially the same general type of machinery, the cost of an individual operation on the same part varied from no difference up to seventeen for the highest cost plant to one for the lowest cost plant. Fortunately for the competitive situation in this area neither all the low-cost nor all the high-cost operations were in one plant. The range in costs usually was caused by better methods, better raw materials, and sometimes by better machines.

Nevertheless, if two plants equally alert to the importance of good methods and efficient use of their personnel use different types of machinery in producing the same part, the one using the best, modern types of machinery will produce the most goods per unit of time. The prime cost¹ per unit of goods, however, cannot be calculated over a few hours or even a few weeks. To get a true cost it is necessary to collect all the costs involved for idle capacity as well as occupied capacity for a much longer time, say one year or longer, and divide by the number of units produced during the period. In other words, profits cannot be increased nor can costs be reduced by idle machinery.

Machinery Buying on False Premises. There has been some high-pressure salesmanship and considerable loose thinking in the consider-

¹ Includes labor and material only.

ation of equipment policies in many plants. Various surveys have shown that a high percentage of the machinery of the nation is over ten years old. This in some quarters is assumed to be bad, particularly when the productivity of the newer machinery is considerably greater. Some factory executives feel that somehow, if new machinery could be installed, production problems would be solved. Shop superintendents and foremen along with production men try to press major executives to make replacements.

The following report² was made to determine the economic feasibility of replacing a machine which was in service for drying rayon fabric.

Cost of Drying Rayon Fabric—Present Method versus Proposed Method

- I. The object of this report is to compare the costs of drying rayon fabric by the following methods:
 1. Present method: centrifugal extractor; looper dryer; mangle.
 2. Proposed method: single unit which combines extracting, drying, and mangling into one continuous operation.
- II. An analysis shows the present cost using the existing method to be \$8.627 per 1,000 lb. of rayon fabric dried; whereas an analysis of the proposed method shows a cost of \$9.783 per 1,000 lb. These costs are based on a 1,500-hour year. The following table will compare the various cost factors:

	Cost per 1,000 Lb.	
	[Present] method [665,000 lb.]	Proposed method [760,000 lb.]
1. Labor cost	\$3.337	\$2.118
2. Power cost	1.118	0.559
3. Maintenance and repairs	0.592	0.592
4. Rental	.....	3.950
5. Steam cost (drying)	0.545	0.488
6. Tax on equipment	0.040	.....
7. Depreciation	1.021	0.986
8. General plant expense	0.663	0.165
9. General overhead	0.339	0.215
10. Supervision	0.759	0.480
11. Steam cost (mangling)	0.196	0.196
12. Light	0.009	0.002
13. Heat	0.008	0.002
14. Conveying fabric to machine	.....	0.030
Total cost per 1,000 lb.	<u>\$8.627</u>	<u>\$9.783</u>

NOTE: The present conveying is considered under other headings.

² *Private Industrial Report* compiled by Alden Elstrom, industrial engineer.

III. Output.

1. A recent test made on Dryer No. 2 showed a production of 3,543 lb. in an eight-hour run. Assuming a 1,500-hour year, the yearly production of this machine is 665,000 lb. The dryer started empty and ran empty at the end of the test. This is a departure from the usual procedure as the dryers are usually filled, the fabric drying overnight. The capacity of the dryer is approximately 500 lb., and, as can be seen, the yearly production is substantially more than is figured in this report. This increased production will, of course, reduce the fixed costs as well as the steam costs.
2. The salesmen for the proposed machine state that it will produce 25 to 36 yards per minute with a slow down required for cutting ends and starting a new piece. In order to convert yards per minute into pounds per minute the following calculations were made.

Average width of roll = 19.4 inches = 0.54 yds.

Average weight = 0.0004 lb. per sq. in. = 0.52 lb. per sq. yd.

Assume proposed production at 30 yds. per minute.

Assume 1,500 hours per year.

The yearly production then equals

$$^0.54 \times 30 \times 60 \times 1,500 \times 0.52 = 758,160 \text{ lb.,} \\ \text{say } 760,000 \text{ lb.}$$

3. Any savings which would be made by the proposed machine due to waste savings, improved quality, etc., have not been taken into consideration because of insufficient data.

IV. Labor Cost.

1. Time studies were made on the various labor elements contained in the present processing setup. Studies were made during the test run on 3,543 lb. of fabric; also several check studies were made. The first table on p. 321 will show the distributed labor costs. An allowance of 15 per cent has been added to all the elements in the table. It should be noted that the operators loading and unloading the dryers work on the other drying machines if production is held up due to slow drying.
2. The salesman for the proposed machine states that two operators are necessary in the operation of this machine. Due to the more complicated mechanism, it is assumed necessary to have one operator at \$0.60 per hour; the other operator is here rated at \$0.40 per hour. Also assuming the present labor costs, for trucking fabric to the extractor and trucking fabric to the elevator, will equal the cost of trucking to and from the proposed machine, there is an additional

Element	Man-Hours per 1,000 Lb.	Rate per Hour	Cost per 1,000 Lb.
Truck fabric to extractor	0.134	\$0.40	\$0.054
Sew ends of rolls	0.129	0.40	0.052
Load extractor	0.662	0.40	0.264
Unload extractor	0.306	0.40	0.122
Unload triplex conveyer	0.645	0.40	0.258
Load dryer	1.970	0.34	0.670
Unload dryer	1.970	0.34	0.670
Mangle	3.220	0.36	1.158
Fabric to elevator	0.223	0.40	0.089
Total labor cost			\$3.337

labor cost of \$0.054 plus \$0.089 or a total of \$0.143 per 1,000 lb. of fabric. The cost per unit in operating the machine then equals

$$\frac{(0.60 + 0.40) 1,500}{760,000} = \$0.001975 \text{ per lb. or } \$1.975 \text{ per 1,000 lb.}$$

$$\text{Total labor cost} = \$1.975 + \$0.143 = \$2.118 \text{ per 1,000 lb.}$$

V. Power Cost.

1. The power cost of the present method of processing has been roughly calculated using the ratings on the various motors used. In converting horsepower to kilowatts, 0.800 kilowatts per horsepower was used in order that some allowance might be made for losses. It should be noted that the power charge for extracting is an average of the six extractors used. The power charge per kilowatt is \$0.02. The following tabulation illustrates the calculation:

Item	Hp.	Kw.	Hours per 1,000 Lb.	Kwhr.	Cost per 1,000 Lb.
Loading extractor	2.0	1.6	0.62	0.99	\$0.020
Extracting (average)	31.0	24.8	0.39	9.75	0.195
Unloading extractor	2.0	1.6	0.32	0.51	0.010
Triplex conveyer	2.0	1.6	0.32	0.51	0.010
Drying	22.0	17.6	2.40	42.20	0.832
Mangling	1.0	0.8	3.20	2.56	0.051
Total cost per 1,000 lb.					\$1.118

2. The literature for the proposed machine states that the power savings range from 10 to 25 per cent. It is thought that the present equipment is somewhat overpowered. Assume the present equipment to be 25 per cent overpowered, this plus a saving of 25 per cent gives a total saving of 50 per cent. This then gives a proposed power cost of \$0.559 per 1,000 lb. of fabric.

VI. Maintenance and Repairs.

1. An examination of the maintenance charges made during 1929, 1930, 1931, and 1932 showed the maintenance cost of the extractors to be 4 per cent of the total charges made against Department 10. These records also showed the maintenance cost of the drying, mangling, and folding equipment to be 40 per cent of the total. The standard maintenance cost for Department 10 is \$3,537. Assuming the 40 per cent to be equally distributed over the four drying machines, the maintenance of one unit would be 10 per cent of the total. It should be noted that the mangles and folders are included in this percentage. The following tabulation explains how the maintenance cost was calculated:

Unit	Maintenance per Year (1,500 Hours)	Hours Equip. Used per 1,000 Lb.	Cost per 1,000 Lb.
Extractor	\$141	0.62	\$0.059
Dryer, etc.	354	2.26	0.533
Total maintenance cost per 1,000 lb.			\$0.592

2. The above maintenance charge amounts to approximately 6.7 per cent of the purchase price of the equipment. It is expected that the maintenance cost on the proposed machine would be somewhat higher than that on the present equipment; however, it is not expected to be as much as 6.7 per cent of its monetary value. Therefore, for comparative purposes, it is felt that a maintenance cost equal to that of the present equipment is very conservative.

VII. Rental.

The rental cost ³ per year for the proposed machine is \$3,000.

The rental cost per 1,000 lb. of fabric is then equal to

$$\frac{\$3,000}{760,000} = \$3.95$$

³ Rental cost was set by the machine's manufacturer. Outright purchase was not permitted.

VIII. Steam Cost (Drying).

1. The steam consumption measured during the recent test run was 5,600 lb. for drying 3,543 lb. of fabric. The unit steam cost is \$0.345 per 1,000 lb. of steam.

$$\frac{5,600}{3,543} = 1.58 \text{ lb. of steam required to dry 1 lb. of fabric}$$

Then, the steam cost per 1,000 lb. of fabric equals

$$1.58 \times \$0.345 = \$0.545$$

It should be noted that the present equipment uses low-pressure exhaust steam.

2. The proposed machine is estimated to have a steam consumption between 1.4 and 1.6 lb. per lb. of water evaporated. Assuming that the squeeze rollers of the proposed machine remove the same amount of water as the centrifugal extractors, the steam cost can be calculated.

During the test on the present equipment, 3,345 lb. of water were evaporated. The pounds of water per pound of fabric then equals

$$\frac{3,345}{3,543} = 0.942$$

or

$$942 \text{ lb. of water per 1,000 lb. of fabric}$$

Taking an average steam consumption of 1.5 lb. per lb. of water for the proposed machine, we have

$$942 \times 1.5 = 1,410 \text{ lb. steam per 1,000 lb. of fabric}$$

Then, the steam cost per 1,000 lb. of fabric at \$0.345 per 1,000 lb. of steam equals

$$1.410 \times 0.345 = \$0.488$$

If the proposed machine requires high pressure live steam, the steam cost will be increased, especially in the summer months when exhaust steam would be wasted.

IX. Tax on Equipment.

The tabulation on page 324 gives the tax costs on the present equipment.

X. Depreciation.

1. The actual depreciation cost of the present equipment is very small as most of the equipment has been written off entirely. It does not seem fair to compare this small depreciation cost with the cost of operating the proposed machine;

therefore, the depreciation rate has been revised for a basis of comparison.

Equipment	Book Value	Tax per Year at 3.5 Per Cent (1,500 Hours)	Hours per 1,000 Lb.	Cost per 1,000 Lb.
Extractors	\$365	\$12.75	0.62	\$0.005
Dryers	403	14.10	2.26	0.021
Mangles	546	19.10	1.07	0.014
Total tax per 1,000 lb.				\$0.040

The following table will show the depreciation costs considering first, the cost based on replacement at the original purchase and installation charge at the actual depreciation rate; secondly, the actual depreciation costs; and third, the cost based on a revised depreciation rate:

[Old] Equipment	Orig. Cost	Year Pur- chased	Dep. Rate Per Cent	Re- vised Dep. Rate Per Cent	Hours per 1,000 Lb.	Cost per 1,000 Lb.		
						Replace- ment	Actual	Re- vised
Trucks (to extractor)	\$ 29	1926	12.50	10.00	0.74	\$0.002	\$0.002	\$0.001
Sewing machines	295	1909	6.67	6.67	0.62	0.008	...	0.008
Extractor loading shaft	106	1915	6.67	6.67	0.62	0.003	...	0.003
Extractor (72 inches)	3,450	1919	6.67	3.33	0.62	0.100	0.100	0.040
Extractor (48 inches)	1,484	1918	6.67	3.33	0.62	0.041	...	0.021
Extractor (40 inches)	660	1907	6.67	3.33	0.62	0.018	...	0.009
Extractor unloading conveyer	935	1927	16.70	10.00	0.62	0.103	...	0.062
Triplex conveyer (¾)	1,200	1927	16.70	10.00	0.62	0.132	...	0.079
Trucks (to dryer)	52	1927	20.00	8.35	6.55	0.045	...	0.019
Openers	44	1926	25.00	25.00	2.26	0.017	...	0.017
Dryer No. 2	5,951	1916	6.67	6.67	2.26	0.598	...	0.598
Trucks (to mangle)	52	1927	20.00	8.35	8.81	0.059	...	0.024
Unit heater	331	1929	10.00	10.00	0.57	0.013	0.013	0.013
Exhaust fan (36 inches)	102	1919	10.00	10.00	0.57	0.004	...	0.004
Exhaust fan (42 inches)	112	1919	10.00	10.00	0.57	0.004	...	0.004
Steam line	75	1916	10.00	5.00	2.26	0.011	...	0.006
Electric wiring	200	1916	6.67	5.00	2.26	0.020	0.020	0.015
Motors—unload extractor	140	1927	6.67	6.67	0.62	0.004	0.004	0.004
Motors—triplex conveyer	140	1927	6.67	6.67	0.62	0.004	0.004	0.004
Motors—dryer	368	1916	6.67	6.67	2.26	0.036	...	0.036
Mangle	299	1927	10.00	6.67	3.21	0.064	0.064	0.043
Motor—mangle	76	1927	6.67	6.67	3.21	0.011	0.011	0.011
Total depreciation cost per 1,000 lb.						\$1.297	\$0.218	\$1.021

It should be noted that where motors, compensators, switches, etc., have the same depreciation rate as the equipment they serve, they have been included as part of the equipment.

2. The original cost of the proposed machine is \$6,500, and plus this there will be the cost of a conveyer and the installation charges. It is estimated that the installation and conveyer costs will be \$1,000 at a minimum. A reasonable rate of depreciation, for comparative purposes, would be 10 per cent. The cost per year then is equal to

$$(6,500 + 1,000) \times 0.10 = \$750$$

The cost per 1,000 lb. of fabric then equals

$$\frac{750}{760.000} = \$0.986$$

XI. General Plant Expense.

1. The general plant expense is distributed on the basis of floor space. The following tabulation will show how this cost was calculated.

Item	Yearly Cost				Cost per 1,000 Lb.		
	Dept. 10 45,191 sq. ft.	Drying 3,170 sq. ft.	Extract- ing 1,260 sq. ft.	Man- gling 682 sq. ft.	Drying (2.26 hr.)	Extract- ing (0.62 hr.)	Mangling (3.21 hr.)
Building depreciation	\$1,399	\$ 98	\$39	\$21	\$0.148	\$0.016	\$0.045
Real estate taxes	2,123	150	59	32	0.226	0.024	0.069
Janitor and upkeep	840	59	23	13	0.089	0.010	0.028
Insurance	37	3	1	1	0.005	0.001	0.002
Cost per 1,000 lb.					\$0.468	\$0.051	\$0.144

The total cost per 1,000 lb. is then equal to \$0.663.

2. The literature for the proposed machine states that the floor space savings range from 50 to 75 per cent. Assuming a saving of 75 per cent, the "General Plant Expense" for the proposed machine would be 25 per cent of the present cost, or \$0.165 per 1,000 lb. of fabric.

XII. General Overhead.

1. The general overhead is the administrative cost chargeable to manufacturing. The cost is distributed on the basis of wages and salary paid in the various departments. The

total charge against Department 10 is \$2,448 per year. The total hourly wage for Department 10 is \$15.81.

Operation	Hourly Wage	Cost per Year (1,500 Hr.)	Hours per 1,000 Lb.	Cost per 1,000 Lb.
Extracting	0.80	\$124	0.62	\$0.051
Drying	0.54	84	2.26	0.126
Mangling	0.49	76	3.21	0.162
Total cost per 1,000 lb.				\$0.339

2. The general overhead cost being distributed on a basis of wages paid will then be proportional to the labor costs per 1,000 lb. of fabric. The proposed cost is

$$\frac{2.118}{3.337} \times 0.339 = \$0.215 \text{ per 1,000 lb.}$$

XIII. Supervision.

The supervision cost for Department 10 is \$5,469 per year. This cost has been distributed in the same manner as the "General Overhead" cost. The cost per 1,000 lb. for each method is:

1. Present method: \$0.759
2. Proposed method: \$0.480

XIV. Steam Cost (Finishing).

1. It is estimated that the mangle steam used at present is approximately 50 lb. per hour per machine. The steam cost then equals

$$0.05 \times 11.4 \times .345 = \$0.196 \text{ per 1,000 lb.}$$

2. It is estimated that, for the same finish, approximately the same amount of steam would be used by the proposed machine.

XV. Light.

1. An average of 720 watts are expended for an average of approximately 400 hours per year. This gives a lighting cost of \$0.009 per 1,000 lb. of fabric.
2. It is assumed that only about 25 per cent of the light will be necessary in operation of the proposed machine. This cost is then \$0.002 per 1,000 lb.

XVI. Heat.

1. The heating cost for the present setup has been roughly calculated, by first estimating the square feet of radiation and from this the amount of steam required. This cost is set at \$0.008 per 1,000 lb. of fabric.
2. The heating cost of the space required by the proposed machine is estimated to be about 25 per cent of the present cost, or \$0.002 per 1,000 lb. of fabric.

XVII. Conveying of Fabric to Proposed Machine.

Some kind of a conveyance will be necessary if the proposed machine is installed. For comparative purposes it has been suggested to use the same costs that exist in conveying fabric from the extractors to the drying machine. The depreciation on this conveyer has already been considered under the heading "Depreciation." The other costs are:

Maintenance	\$0.016
Power	0.010
Tax	0.004
	<hr/>
Cost per 1,000 lb.	\$0.030

XVIII. The foregoing costs are based on a yearly (1,500 hours) production of 665,000 lb. of rayon for the present method, and 760,000 lb. for the proposed method. The cost per unit will, of course, vary with the production. For this reason a curve has been drawn for each machine to show the variation in cost with production. The yearly costs for the 1,500-hour year are:

1. Present method: \$5,736.96 for production of 665,000 lb.
2. Proposed method: \$7,435.08 for production of 760,000 lb.

It is only necessary to find one more point for each curve and since practically all of the comparative costs between the present and proposed methods either remain the same or vary directly with the production, the total costs for the various production totals will also vary directly, falling on a straight line curve. Such fixed items as rental, taxes on equipment, depreciation, and general plant expense are distributed over the current production. The cost of light and the fabric conveyer are not proportional to the production but since their effect is so small on the total cost it is assumed they are also proportional to the current production.

If the production of each machine is doubled the unit costs are as listed below:

MACHINE REPLACEMENT

	<i>Cost per 1,000 Lb.</i>	
	<i>Present method</i> <i>(1,330,000 lb.)</i>	<i>Proposed method</i> <i>(1,520,000 lb.)</i>
Labor	\$3.337	\$2.118
Power	1.118	0.559
Maintenance and repairs	0.592	0.592
Rental	.....	1.975
Steam cost (drying)	0.545	0.488
Tax on equipment	0.020	.....
Depreciation	0.511	0.493
General plant expense	0.332	0.083
General overhead	0.339	0.215
Supervision	0.759	0.480
Steam cost (mangling)	0.196	0.196
Light	0.060	0.020
Heat	0.008	0.002
Conveying fabric to machine	.....	0.026
	<hr/>	<hr/>
Total cost per 1,000 lb.	\$7.817	\$7.247

As can be seen the unit cost of the proposed machine, operating 3,000 hours per year, is less than the present method. The yearly cost (3,000 hours) is:

1. Present method: \$10,396.61 for production of 1,330,000 lb.
2. Proposed method: \$11,015.44 for production of 1,520,000 lb.

Plotting these two points and the two points for a 1,500-hour year, a curve can be drawn for each method to show the cost variation with production. The two curves cross at approximately 1,400,000 lb. which indicates that for a production greater than that figure the proposed machine is the most economical.

- XIX. For a yearly production of 760,000 lb. the rental of the proposed machine should be about \$2,000 per year in order to produce at the present cost.

At the time this report was written it would have been unwise to install the machine because the added cost per year would have been about \$7,700.00 for the rayon fabric then produced (based on a production of 665,000 pounds at a saving of \$1.16 per pound). In addition the old process employed more labor. The labor not needed for the proposed process would probably have been added to the unemployed group during this depression period. Thus uneconomic mechanization may also become a social problem.

Since this report was written in 1933 the production of rayon fabric in the plant has increased to considerably more than 1,000,000 pounds per year. Moreover, national defense contracts in 1941 and 1942

further increased this production. These new production rates coupled with the fact that the rental of the machine was reduced from \$3,000 to \$1,800 per year made it worth while to install the machine in 1941. The break-even chart, shown in Figure 1, made the report more valuable because it predicted when the proposed machine would be economically feasible.

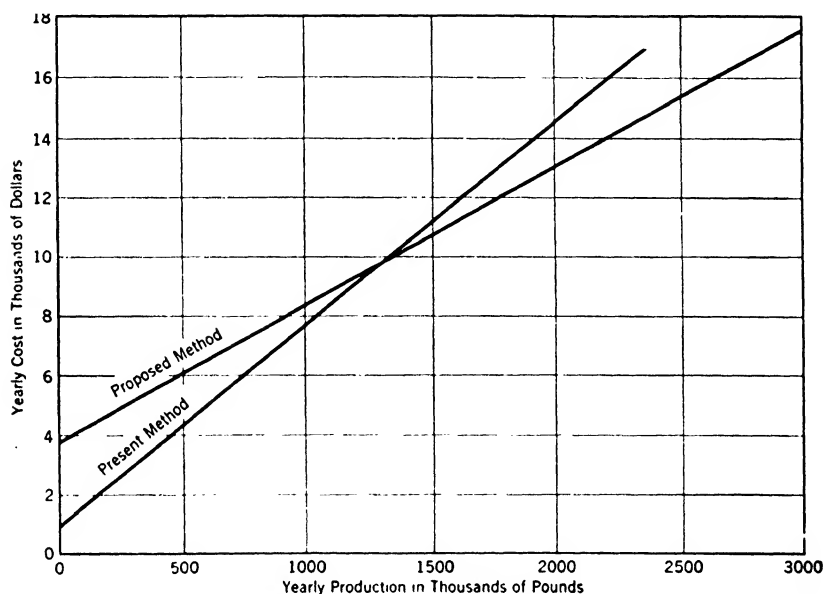


FIGURE 1. Cost comparison based on yearly production for present and proposed methods.

Mistakes in Machinery Purchasing. The late W. M. Vermilye in his paper *Economic Trends in Manufacturing and Sales* pointed out that all proposed additions to capital investments should be made only after the most careful study. Extravagance in payment of salaries or buying materials too good for a product is wrong and foolish but can be stopped at almost any time necessity may demand; but extravagance in expenditure for capital assets commits the company for the life of the asset to a cost of at least 15 cents a year for every dollar spent. Overexpanded plant capacity takes its toll from the overhead account as long as the cost to the consumer can be sufficient to cover. Sooner or later, however, the consumer finds a vendor whose costs do not have to include overhead on idle equipment and then the overexpanded company must get its burden charge from the profit-and-loss account which may be mostly loss.

Effect of Age on Machinery. The age of a machine is not an infallible criterion of the condition of a machine. A machine that is speeded beyond its rated capacity may deteriorate more rapidly than one operated at its normal speed. In fact, most machine guarantees are voided if the machines are run faster than the rate set by the manufacturers. Factory owners do this only when they know increased production resulting from faster speeds will pay for the shorter life of the machine. Moreover, since they never can be sure in the bewildering whirl of mechanical inventions and improvements when a machine will become obsolete, it is better to build the depreciation reserve faster so that early obsolescence does not create a loss in the capital account.

The age of a machine may indicate in a general way its usefulness in a factory. A machine over thirty years old is likely to be too worn to function efficiently or to produce acceptable work. More important still, it is almost certain to be obsolete and ordinarily a manufacturer who uses it cannot compete with other plants which have more modern machinery. However, each machine should be analyzed to see if it can compete under the conditions in the plant. Occasionally an old model may be exceptionally good. A certain producer of linseed oil who wished to enlarge his plant wanted to install the best equipment he could find. He combed the world's markets, and in the end bought duplicates of the machinery he had been using for twenty-five years. This of course may have two implications: First, designers of the machines and process which had been in use over twenty-five years were master technicians far ahead of their time; or second, designers in the field have become short-sighted and need new blood to provide inspiration.⁴

New Machines as an Asset. However, no one should assume that new machines are a menace to good business or that additions to the capital investment often raise the cost per unit of product. There are, no doubt, many industrial plants that are losing money by failure to purchase badly needed equipment. Often an inspection of the list of machinery or a visit to the plant of a bankrupt concern offers the best evidence that antiquated machinery does not produce dividends.

In most communities there are examples of establishments of one kind or another with no policy for replacing obsolete or decrepit equipment. Modern banks are likely to criticize the executives of

⁴The same company has since purchased two new-type continuous screw presses to replace the old hydraulic batch presses.

such companies because all too often the fundamental concept⁵ of depreciation reserves has been ignored.

There are hundreds of examples in factories and offices of savings that have paid for the necessary equipment in one year or less. No company can afford to neglect such savings if they are genuine, that is, if the current production is sufficient to produce the calculated savings.

Replacement Procedures. In well-managed plants the original purchase or replacement of all machinery is carefully studied for each individual situation. There are mathematical relationships to be obtained from the data which aid the judgment of the responsible executive. It is true that assumptions must be made at certain points in the gathering of these data; yet, if a recognized practice is followed wherever possible and if records are kept of the assumptions made, a firm can build up its ability to weigh objectively the various factors. Considerable executive judgment must be exercised on the relationships between the tangible and intangible factors, but careful planning based on complete data will greatly reduce mistakes of over- or under-buying equipment.

Replacement Policies. Some companies have policies of continuous replacement under which depreciation funds collected as a part of the cost of doing business are spent at regular intervals. The Blanchard Machine Company⁶ advocates that at least 10 per cent of the replacement value of all tools be spent each year to replace old or obsolete machines. Any extensions to the plant should be paid for by additions to this sum. The Blanchard Company believes that:

1. It is usually profitable to replace a ten-year-old machine tool.
2. Money set aside for depreciation should be spent regularly.
 - 2.1 Depreciation and obsolescence are continuous and should be met by continuous replacement to keep abreast of modern shops.
 - 2.2 Money invested in machine tools will earn more than it will in securities.
 - 2.3 Depreciation reserves, if allowed to accumulate instead of being used to replace equipment, are a constant temptation for use in other ways.
 - 2.4 There is less resistance by officers when equipment purchases are made at regular intervals instead of occasionally in large quantities.

In the Blanchard plan the shop superintendents keep a list of tools whose age, condition, and performance do not compare favorably with

⁵ Fundamentally, depreciation reserves are set up to recover equipment costs from the customer and to provide funds for purchasing replacements.

⁶ *American Machinist*, Vol. 75, pp. 798-802.

more recent designs. The machines showing the greatest chance for improvement are the ones to study for replacement. If subsequent study indicates that replacement will mean more profit, the new machine is purchased.

A survey conducted some years ago showed that almost 60 per cent of ninety-one firms in all lines of business required that equipment pay for itself within a definite period. The time varied according to the type of machinery. Special machinery must pay for itself quickly, from six months in extreme cases, where highly seasonal or rapidly changing products are machined, to two years for machines producing moderately stable goods. General-purpose machines used in jobbing shops or even special types of machinery used for packing staple products, like gelatin dessert powder, spices, or Portland cement, are purchased if they can save their cost in from five to ten years. Few factory executives would replace a machine in good working order with a new machine which would require more than ten years to save its cost.

During a period of high income taxes for corporations, it is not wise to assume that an apparent saving made by new equipment is available for use by the company. It is much more conservative to assume that machine replacement studies should be based on the savings after taxes.

Justification for New Machinery. New machinery is not always purchased to reduce cost but sometimes because new machines are needed to produce a larger part, a better finish, a smaller tolerance, better service to customers, better factory conditions for the workers, or to prevent enlarging space requirements as new machines often produce more per square foot of floor space than do older models.

Depreciation Policies. Although many companies require that machines repay their costs within rather limited periods, say from one to five years, they charge the cost of all equipment to the capital account and depreciate it at regular rates for the type of machine in question. This depreciation is charged regularly to the operating expense and appears in the cost of production.

When a new machine is to replace one which is about to be sold or junked but which still has a book value, the undepreciated amount must be removed as an asset of the company. Two general methods are in use with most manufacturers favoring placing the unamortized balance in the profit-and-loss account. Some manufacturers subtract the undepreciated sum from the possible savings to be produced by

the new machine. In other words, under the second method, the proposed saving of the new machine should pay for any remaining book value before it becomes a real saving in cost of manufacture.

Who Determines Machine Replacement? Manufacturing executives and engineers are responsible for discovering the need for and specification of equipment in practically all plants. They keep abreast of the times in a number of ways, none of which can be neglected. Magazines in the various fields always carry advertisements and articles describing new machines and processes with auxiliary equipment. Meetings of trade, engineering, and management groups, both local and national, and plant visits to similar or allied lines of manufacturing are important sources of inspiration and can give concrete illustration of what others are doing. The era of secret processes and methods secured with secret machines and equipment is almost gone. Most manufacturers believe now that plant secrets tend more to keep new ideas from coming into the plant than they do to keep others from copying.

Analyzing the Need for Machinery. The exact procedure and routine used to select, buy, and finance equipment will vary widely from plant to plant but this is not at all important. It is important, however, that the selection of machinery and its desirability be carefully analyzed with due respect given to all the factors by someone in the organization who thoroughly understands the problems and how to approach them.

There have been a large number of formulas and methods of analysis suggested, many of which are equally satisfactory. Any formula of this nature should not be used, however, unless its derivations and limitations are clearly understood. For this reason, some concerns do not use formulas but fill out forms with credit and debit items which can be evaluated separately. This method sometimes makes it easier to review each item more critically. If a large number of calculations are to be made for similar machines, it is much easier to set up the relationships in formula form, but for the semioccasional analysis the balancing of items on a prepared form may lead to fewer mistakes.

The Warner and Swasey Company⁷ advocates the use of an equipment replacement statement as shown in Figures 2 and 3 for the average lot plant. They estimate that about 75 per cent of metal-working production in the United States falls in the average lot group of fifteen to fifty pieces per lot. In this type of manufacturing, it is better

⁷ *American Machinist*, Vol. 75, pp. 836-853.

to measure performance of a machine by including the many jobs to be done on a machine rather than one or two of the most spectacular time-saving jobs.

EQUIPMENT REPLACEMENT STATEMENT

(For data see reverse side)

Old Machine Name_____ Machine No._____ Date_____

Proposed Machine Name_____

		Credits	Debits
Saving per year in direct labor and labor burden	(Item E)	\$000.00	\$.....
Saving per year in power and supplies	(Item F)	.....	00.00
Saving per year in maintenance and upkeep	(Item G)	0.00	.....
Saving per year in usable floor space	(Item H)	0.00	.....
Saving per year in material costs	(Item I)	00.00	.....
Saving per year in fixed charges	(Item L)	.....	000.00
Saving per year in unusual charges	(Item X)	000.00	.....
		<u>000.00</u>	
(Item M) Net savings, based on_____ % activity (Item B)		\$000.00	
(Item K ₂) Investment for proposed equipment ready to produce		\$0000	00
(Item K ₁) Less net resale value of old equipment		<u>00</u>	<u>00</u>
(Item N) Net cash investment in proposed equipment		\$0000	00
(Item O) New equipment will pay for itself in			
		$\frac{\$0000.00}{\$000.00}$	$\frac{(\text{Item N})}{(\text{Item M})} =$
			0.0 years
(Item P) Rate of net profit on additional investment			
		$\frac{000.00}{0000.00}$	$\frac{(\text{Item M})}{(\text{Item N})} =$
			____%

FIGURE 2

Basic Facts for Analysis. Four basic facts are needed to determine when it is profitable to replace machinery.

1. What is the actual saving in production time by use of new equipment? This actual total saving in production time computed for all jobs to be run on the proposed machine, including the prorated setup time, will remove the possibility of basing the decision on only one or two of the most spectacular time-saving jobs. Where the machine is to be used on long runs of several hundred pieces or more,

DATA FOR PROCESS ON BOTH OLD AND PROPOSED MACHINES *

1	2	3	4	5	6	7	8
Job number or description of all parts to be run on new machine	Operation number	Number of pieces or lb. required per year	Time per piece or lb., etc., with setup time prorated (minutes)		Time in hours for the number required per year		Remarks
			Old Machine	Proposed Machine	Old Machine Col. 3 × Col. 4	Proposed Machine Col. 3 × Col. 5	
					60	60	

* This information is usually placed on the back of Figure 2.

(Item A) Hours saved per year; (Col. 6 ____ hrs. - Col. 7 ____ hrs.) = ____ hrs.

(Item B) Percentage of year proposed machine will operate

$$\left(\frac{\text{Col. 7 ____ hrs.}}{\text{working hrs./yr.}} \right) = \text{____ \%}$$

(Item C) Saving per hour in direct labor (old machine \$____ per hr. - proposed machine \$____ per hr.) = \$____

(Item D) Labor burden (part of factory burden incurred because labor is present) ____ %

(Item E) Saving per year in direct labor and labor burden
 (Item AC + ACD) = \$____ Credit
 Debit

(Item F) Saving per year in Power and Supplies (old machine \$____ - proposed machine \$____) = \$____ Credit
 Debit

(Item G) Saving per year in maintenance and upkeep (old machine \$____ - proposed machine \$____) = \$____ Credit
 Debit

(Item H) Saving per year in usable floor space (old, ____ sq. ft. - proposed ____ sq. ft. = ____ sq. ft. at ____ /sq. ft.) = \$____ Credit
 Debit

(Item I) Saving per year in material (old cost - proposed material cost) = \$____ Credit
 Debit

(Item J₁) Taxes and insurance (____ %), plus allowance for depreciation (____ %), plus allowance for interest (____ %) = ____ % for fixed charges on old equipment = ____ %

(Item J₂) Taxes and insurance (____ %), plus allowance for depreciation (____ %), plus allowance for interest (____ %) = ____ % for fixed charges on new equipment = ____ %

(Item K₁) Investment in old equipment = \$____

(Item K₂) Investment in proposed equipment (ready to run) = \$____

(Item L) Difference in fixed costs (J₁K₁ - J₂K₂) = \$____ Credit
 Debit

(Item X) For occasional credits or debits not ordinarily encountered = \$____ Credit
 Debit

FIGURE 3

the setup time is relatively unimportant. However, for short runs of less than fifty pieces, the exclusion of setup time can seriously unbalance the decision toward the wrong side. The sample should include, if possible, all the jobs which ordinarily would be run on the proposed machine. The total number of units to be produced per-year for each job to be run on the proposed machines can be estimated. If this estimate (column 3 in Figure 3) is multiplied by the number of minutes, including prorated setup time for each lot run (columns 4 and 5, Figure 3), it will give the number of minutes necessary per year to produce this particular part. Columns 6 and 7 carry this item in hours per year for old and proposed methods. The sum of the hours per year necessary to produce all the units which are to be run through the machines (totals of column 6 and column 7) will give the total hours' use of old and proposed machines during a year's time. If the new process or machine does have idle capacity for the year, then any unforeseen parts which can be run on the machine will increase the percentage of time used and make the machine produce more net profit than originally calculated. This saving in turn is listed under Item A in Figure 3.

2. What is the dollar value of the time saved per piece if the new machine is purchased? The wage rate of the man or men whose time is saved can be multiplied directly by the hours saved per year. The factory overhead, generally based on direct labor, is not all spent for items which can be curtailed in proportion to labor time saved. Such items⁸ as power plant, drafting room, tool room, pattern room, small tools, defective purchased finished material, purchasing, and other expenses will go on even if the plant becomes automatic and requires very few men to operate the various machines. In fact, some of the items mentioned above may increase the overhead account as more mechanized machinery with high overhead costs is placed in the plant. Such expenses as supervision, employment office, certain supplies, compensation, hospitals, sick and death benefits, inspection, defective work and other items are generally incurred because labor is present. Consequently, for conservative action, it is not wise to calculate on saving all the factory burden charged against the direct labor saved.

For example, it was found that in one plant the labor burden was about 40 per cent of the total factory burden. At the Warner and Swasey plant, the labor burden was about 78 per cent of the total burden. From these figures it can be seen that gross errors would

⁸ For detailed method of splitting the ordinary factory burden into labor and factory burden accounts for calculation purposes, see *Transactions of the American Society of Mechanical Engineers*, Vol. 47, pp. 529-534.

have resulted if the proposed new machine had been purchased on the assumption that all of the factory burden could have been saved. Since the labor burden percentage of the total burden does vary widely from one type of plant to another, it should be calculated periodically to get a good average figure for use in equipment replacement calculations. The labor burden percentage to be charged against direct labor is listed under Item D in Figure 3.

3. What per cent of the total productive capacity of the proposed machine can be used during the year? The number of hours of use of the machine is calculated in column 7 of the data sheet (Figure 3) if the number of units of each part required from the proposed machine during the year can be estimated. The percentage of activity is shown in Item B in Figure 3.

4. What is the exact investment required? This cost should include all the costs of installing the proposed machine in the shop, ready to run with all the special tools necessary to produce the various jobs planned for it.

The Cost Balancing Method. Though many different types of formulas have been developed to calculate the desirability of replacement, it is easier to use for this calculation a credit and debit form such as shown in Figures 2 and 3. Moreover, the form provides a definite procedure which reduces errors and furthermore provides a record of the calculations which can be filed for future reference and checking.

This form makes provision for relative costs of power, maintenance, supplies, space requirements, difference in material requirements, taxes, insurance, interest, investment, and depreciation. Though not all these items are valid in every study, they can be left blank if they are not potent factors. Usually, the combined percentage allowance for taxes, insurance, interest, and depreciation is the same on both old and proposed equipment. The remainder of the items, such as power and supplies, may be larger for the proposed machines, or they may be smaller. Each is an individual problem and the amounts must be determined before the proper credit or debit is known.

Unamortized Book Value. To use intelligently any formula or credit and debit statement, such as shown in Figures 2 and 3, it is necessary to understand how the terms and final results are derived. Some replacement formulas attempt to charge in some way any remaining book value of old equipment to the savings or to the investment required for the proposed machine. Many firms feel, however, that if a replacement study shows that a machine has become obsolete enough

to make a new machine desirable, and that if the old machine was not depreciated fast enough to be off the books by that time, then the blame should be on the person who set the depreciation rate. The rate of depreciation should have been higher for the old machine, but since some book value remains, it means that this amount was not charged in the cost of producing the product and consequently was not collected from the firm's customers. This loss is similar in effect to losses caused by poor credit risks, for the past customer gets something without paying for it.

Replacement studies should be made independently of the general accounting records because these records are historical whereas replacement studies are projected into the future. Considerable objection is often raised to reducing the book value of assets too suddenly. But when obsolescence creeps into a plant, the accountants' books may show assets in the form of supposedly good machinery which the plant does not possess. Dividends may be declared during the time when actually these funds are needed to rehabilitate a run-down plant. Because obsolescence is so unpredictable, many establishments set up a replacement or obsolescence fund to which excess book value of an obsolete machine may be charged when any machine is replaced.

Value of Replacement Studies. Depreciation accounting is theoretically set up for the purpose of distributing capital costs of machinery to the cost of producing goods in an equitable manner. At the same time, the capital of the business must be maintained as nearly constant as possible. Actual practice may vary considerably from the theoretical ideal, largely because no one can foresee future improvements in machinery and methods. Average theoretical depreciation rates have been compiled and, if the science and art of producing the goods remains about constant during the predicted life, the machine is usually able to produce effectively at least until its book value reduces to zero. However, periodic replacement studies are a much better method of checking the useful life of a machine than depending entirely on book value.

When an establishment underestimates the quantity of labor or material expended on an order, the loss incurred reduces the profit or may even create a loss. To charge such a loss consistently to future orders in a modern competitive situation would soon drive costs beyond what the customer could or would pay. Likewise, when depreciation is underestimated, the resulting loss cannot be charged to future orders. Eventually, losses such as these must come out of profit and loss or a special reserve fund set up as a buffer for such

errors in judgment. L. P. Alford in *Cost and Production Handbook*⁹ states, "It is axiomatic in business that past losses must not be charged to future costs."

Value of Old Equipment. The value of old equipment is the net realizable value after removal expenses have been paid. The difference between this and the book value is an amount chargeable to the profit-and-loss account. From the total cost of buying, installing, and tooling the proposed machine, the realizable value of the old machine is subtracted to get the net investment or additional cash necessary for the new machine. Sometimes the old machine has a negative value due to conditions which make the cost of removing the machine more than it is worth. If this is true, to this excess removal cost over the value of the old machine must be added the remaining book value of the old machine. The algebraic sum of these two is charged to the profit-and-loss account. Under these conditions the investment for the proposed machine (Item K_2) would be the same as the net investment (Item N) because nothing could be realized from the old machine.

Net Investment. The net investment (Item N) is the additional investment required so that the number of years to pay for investment (Item O) and the rate of net profit (Item P) are based on the cash actually expended for the new equipment rather than on the value of the total investment.

Value of Increased Capacity. Some discussions on replacement policy attempt to evaluate the worth of increased capacity from a new machine which is not completely loaded at the time of installation. This additional capacity does have value if it can be used some time in the future, but it is far more conservative to base replacement studies on present production. If some or all of the additional capacity to produce can be used immediately, the value of this added production over that stated in column 3 should be calculated and entered as a credit for the proposed machine in Item X. This credit is equal to: [minutes saved per piece (column 4 - column 5) \times pieces produced per year out of unused capacity + pieces in column 3]/60 = hours saved per year by producing this additional number of pieces by the old method. The hours saved \times (Item C + CD) = saving per year in direct labor and labor burden for the additional capacity which can be used immediately = Item X. Fixed burden costs, such as represented in Items J_1 and J_2 tend to be constant throughout the year though the variable burden costs, such as those represented in

⁹ Ronald Press, 1934, p. 781.

Items E, F, G, and H, are operating costs which tend to go up and down with production. Item I represents the saving which sometimes comes from a change of materials. It is directly proportional to production. Any of these variable costs for the proposed machine may be positive or negative in value when compared to the old machine and should be labeled credits or debits accordingly.

Item E is calculated in part from Item A which is based on the estimated number of hours per year the proposed machine is to run. Consequently, the saving in direct labor and labor burden is based on the percentage of activity of the machine during the year.

Effect of Power, Repairs, Space, and Material Costs. Items F, G, H, and I should be based on the actual costs incurred during the year for the machines being compared. Item F, power and supplies, varies quite closely with production if the machine is directly connected to power sources except for possible standby service charge when the machine is idle. If a machine is one of several connected to a line shaft the cost for power is not so easily reduced when the machine is idle.

Item G, maintenance and repairs, is largely an annual cost which is independent of activity during the year provided the machine is used a reasonable percentage of the time.

Item H, saving in floor space, may have a zero value unless it is actually used for some other purpose to which it can be charged.

Item I, saving in material, applies only when the material to be used on the proposed machine is cheaper than the one used on the old process. For instance, a Lindemann machine will produce wide boards by building them from pieces of lumber. Scrap lumber, odd-shaped pieces, and even lumber with defects and knots, can be utilized by the dovetailed, glue-joint construction to build up boards from small clear pieces. These synthetic wide boards would be more expensive and, frequently, not so good if they were made directly from first-class wide lumber. The saving in material during the year with a Lindemann machine would be determined by the activity of the machine. In many operations on machines this Item I would be zero.

Interest Charges on Equipment. Interest on the increased investment is a cost which may properly be charged against the proposed machine. If the money had not been spent for equipment it could have been used for other purposes or loaned at some rate of interest. Therefore, the study should show how much more than simple interest the investment in equipment can earn. Simple interest is usually charged at the beginning of the year only on the depreciated value of the equipment. If we assume the generally used straight-line

method of figuring depreciation, where the book value decreases each year by the same amount, the values of the interest, tax, and insurance charges can be calculated to give an average value over the estimated life of the machine. If x per cent is the rate of simple interest desired on the actual capital left at the beginning of each fiscal year until the book value is zero, something less than x per cent can be used on the entire investment over the same time. In other words, if 6 per cent is desired on the original investment for one year and on each depreciated value for one year until the book value is zero, then over a period of years the interest, if figured on the original investment for the same number of years, would approach one-half of 6 per cent, or 3 per cent. The exact value of the lesser interest rate $Y = \frac{1}{2} \times (N + 1)/N$.

The corrected interest rate Y is applied to the total investment over the estimated life, and the rate to be applied for taxes and insurance can be calculated in the same way.

The depreciation and obsolescence rate in Items J_1 and J_2 is taken from standard tables as shown in *Cost and Production Handbook*.¹⁰ The sum of the depreciation, corrected interest, tax, and insurance rates are added together to give a compound percentage rate to make up Items J_1 and J_2 .

The results from a replacement study are no better than the data from which they are calculated. If only one or several products are to be made on the machine it is not difficult to get these data, but if a study is to be made in a job-lot shop then these data are largely estimated for the various products which may be run through the machine. The principles involved in the calculation for one product or many products to be produced on one machine are identical, after the load in number of hours per year is determined.

Replacement Studies Are Important. The selection of new and the replacement of old or obsolete equipment are important phases of managing any business. The cost analyses recorded on forms such as Figures 2 and 3 are a valuable aid in judging whether equipment should be purchased or not. Though cost of producing the product is not always the deciding factor in buying a machine, nevertheless it is an important point which can seldom be entirely neglected. Too often machines are purchased in the hope that they will solve factory problems when, if careful analyses were made, the trouble would show up elsewhere. Many a new machine has placed an unnecessary burden on the factory simply because its purchase was not carefully

¹⁰ L. P. Alford, Ronald Press, 1934, pp. 1243-1269.

studied. Old machinery may not be obsolete though machinery only a few years old may be very obsolete. Each case is a unique problem for individual attention.

Most all modern companies have an equipment replacement policy which tends to keep the factory and office machines in a first-class competitive position with other similar concerns. The policy should include standard periods of time for different types of machines to repay their cost and methods of absorbing values still on the book when old machines are replaced. In addition, someone should be delegated to search for the machines which should be replaced.

From a production control viewpoint, the selection of machinery is important because machinery determines plant capacity which in turn controls the scheduling and the quantity of product which can be processed in any given time.

PROBLEMS AND QUESTIONS FOR DISCUSSION

Collateral reading is necessary for best results.

1. Under what conditions could a twenty-year-old machine still be considered economically fit for service?
2. What are the social implications of machine replacements?
3. Are capital investments subject to greater risk than inventory risks? Why?
4. Wherein do economic considerations differ in the replacement of a pleasure automobile and a machine tool?
5. How can the requirement that a machine must pay for itself in two years be justified if the machine is depreciated in a ten-year period after purchase?
6. Under what conditions is the cost of production from a new machine a secondary matter?
7. When should a new machine not be purchased to replace an old one which has been completely written off the books?
8. Why do ordinary manufacturing plants try to recover the overhead costs of their machinery in forty hours per week?
9. Can you defend the calculation of machine replacement by production engineers rather than by depreciation accountants?
10. State the arguments advanced on both sides of the question of whether unamortized cost of old equipment should be charged against its replacement?
11. Can interest charges on equipment be justified? What happens to profits if they are not charged?
12. A machine shop has been transporting castings weighing from $\frac{1}{2}$ pound to 20 pounds from one department to another by hand trucks. Truckers receive 80 cents per hour and work forty hours per week. It has required an average of 10 trucks to transport the castings. Five dollars per year have

been spent on the average for each hand truck during the last year for maintenance and other services. It has been proposed to use power equipment to transport the castings on skid platforms. The investment in the power equipment and skid platforms has been estimated at \$6,700. Two tractor operators at \$1.00 per hour will be used to transport all the castings. Power and lubrication costs for the two tractors will be \$22 per week. Maintenance and repair costs for each tractor start at \$200 per year for the first year and increase \$50 each year until the tractors are no longer economical to keep. Depreciation, taxes, insurance, and interest on investment of \$5,200 for the tractors are 22 per cent. For the steel skid platforms the depreciation charges are 11 per cent. Salvage value of the old hand trucks is \$5 each, but an unamortized book value of \$8 still remains. The conservative management requires this class of equipment to repay its cost in two years. Assuming the plant operates fifty-one weeks per year, can the investment be justified?

13. Compare the report for the proposed machine to dry rayon fabric with the method outlined in Figures 2 and 3. Wherein do the calculations in the two reports differ, and can this difference be justified?

14. Use the data collected for the report on the drying of rayon fabric with the method outlined in Figures 2 and 3. What difference would there be if these data were recalculated by the suggested method in Figures 2 and 3?

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CHAPTER XVI

COOPERATION WITH COST ACCOUNTING

It is important that production control and cost accounting departments have mutual respect and confidence in each other. The operation sheets, planning records, and detailed labor data of the dispatching procedure may be a medium also for gathering cost information.

Cost Accounting Data from Planning Records. Cost records, to have a maximum value, should be current and not historical. In fact, the quicker the records of cost are made available after an order is completed, the more valuable this record becomes as a control on the cost of future orders. Historical costs, on the other hand, which are available only after a considerable time has elapsed, may be too far removed from current conditions to be of much value in guiding current performance. The successful executive is interested in present conditions and in trends which may indicate necessary future changes. When cost records are available shortly after the completion of the various jobs, any undesirable condition can be corrected before too much damage is done.

It usually is quite difficult to secure separate cost data from production executives or department heads. These men are primarily interested in producing acceptable goods for delivery on a specified date. If they are asked to keep detailed records of cost in addition to their other duties, these records may receive secondary consideration and thus may not always be reliable.

Cost and payroll data, obtained from production control through its regular system of administrative forms, are current information and are as accurate as it is possible to get. Little or no extra expense is involved in gathering these cost data in this manner as they become a by-product of the planning and dispatching records which are made available simply by reproducing additional copies for cost accounting.

Production Control Forms Should Also Be Coordinated for Other Uses. Production control forms (see Chapter XXIII) should be designed not only to satisfy the needs of the production and administrative departments; the data should be grouped and presented in such a way that they may be used for posting cost and payroll records.

contains the same manufacturing order information as the operation sheet of Figure 9 in Chapter XI. In fact both forms were duplicated at the same time and the cost record sheet was sent to accounting as soon as the manufacturing order was released by the scheduling group.

Copies of the material requisition and the inspection tickets (see Figures 4 and 7, Chapter XXIII) are delivered to cost accounting by messenger when the information required on these forms can be reported. As labor hours are reported at the completion of each operation the value is computed and posted. At the same time the percentage of overhead for each department or process center is used to calculate the labor burden or overhead charge. Thus the total factory cost of the manufacturing order can be computed soon after it is finished. When the final copy of the inspector's report which discloses the total number of good and scrapped pieces is at hand, cost accounting can easily calculate the unit cost and the cost of scrap for the order.

When standards are used for cost accounting the labor and material costs are taken from either assumed or average values for each part or material made. Any deviations from standard from period to period are called variations and are charged to the account responsible. Occasionally, if the variation is too great, the standard may be checked by compiling averages of actual costs over a given period to determine whether the old standard cost has changed and why. Standard costs are widely used in many types of industries, but one should be sure that they are not too far from the actual costs, particularly if the plant manufactures a widely divergent line of goods. Production control records and current forms can always provide information for checking the cost standards from time to time.

When standard costs are used, the inspection reports seldom are used as a basis to calculate unit costs. It is assumed that normal scrap is part of the selected standard cost and is applied to product cost through the application of the factory overhead. However, since an excess of scrapped material under a system of standard costs may be an important source of loss in some industries, a daily scrap report, such as shown in Figure 2,¹ will often prove profitable. This report is posted daily to inform all interested executives how much material and labor is currently being wasted and who is responsible. It is difficult to produce any quality product without some scrap, but any process producing over a reasonable amount of scrap should be immediately analyzed to determine the cause.

¹ Developed by Theodore Ryan, Management Consultant. Minneapolis, Minnesota.

SCRAP REPORT														
Date	Part Name	Part Number	Quantity Scraped	Reason Caused by			Reason for Scraping	% Complete Material Recovered	Material Recovered Amount	Standard Cost	Scrap Value		Unrecovered Scrap Loss	
				Feb.	March	April					Feb.	Other		
4/3	Cylinder—2-Speed Pump	1847	892510085	1	1		Sandholes	60	Advance	\$ 15.29	\$ 6.95		\$ 8.34	
4/7	Cam Handle—2-Speed Pump	1847	890111180	2	2		Blowholes	100	Smith	.48	.06		.42	
4/7	Connecting Rod—2-Speed Pump	1849	890811304	2	2		Reamed oversize	100	—	2.22		.02	2.20	
5/2	Leather Retainer—4" Cyl.	1851	936211190	3	3		Blowholes	100	Smith	6.09	.69		5.40	
5/3	Leather Retainer—5" Cyl.	1852	521610886	4	4		Holes reamed over-size	100	Acme	2.16		.09	2.07	
5/7	Cam Rods—D Pump	1853	4958Stock	3	3		Broken during flattening	100	—	1.95		.01	1.94	
5/7	Valve Cap—4-Way Valve	1854	589910976	6	6		Pitch dia. under-size	100	—	9.60		.02	9.58	
5/10	Bronze Cyl.—4-Speed Pump	1856	0511510772	6	6		Ball seat drilled oval shape	100	Advance	49.32		5.04	44.28	
5/10	Piston—4-Speed Pump	1857	0511610772	1	1		Hole drilled over-size	100	—	2.83		.01	2.82	
5/10	Ring Gear Housing—Track Wrench	1858	4550 9631	1	1		Blowholes	30	Smith	9.09		4.50	4.59	
5/10	Base—4-Speed Pump	1859	0511111215	4	4		Broken legs and blowholes	(3) - 0 (1) - 80	Western	9.60	7.80		1.80	
5/11	Leather Retainer—4" Cyl.	1860	936211190	3	3		Blowholes	40	Smith	3.29	.69		2.60	
5/11	Leather Retainer—4" Cyl.	1861	936211192	2	2		Broken during turning	50	Smith	3.70		.46	3.24	
5/13	Ram Piston	1894	936311187	35	35		4" short-drawing error	50	—	80.50			80.50	
5/13	Ram	1895	0924211188	35	35		4" short-drawing error	50	—	87.50			87.50	
5/13	Valve Body	1902	970111606	2	2		Rough bore	100	—	11.12		.17	10.95	
5/15	Crank—D Pump	1904	490411604	1	1		Oversize bore	100	Acme	3.30		.13	3.17	
5/15	Spring—5" Cyl.	1906	2237Stock	1	1		Crooked	100	—	1.43			1.43	
										\$299.47	\$16.19	\$10.45	\$272.83	

FIGURE 2. Report for analyzing excessive scrap when standard costs are used.

The scrap reports are posted daily by the dispatchers for each dispatch area. These area reports may be assembled daily and the figures may be combined to issue a single report, or the several sheets may be used "as is" for the report. In small shops the report may remain in the dispatch station and be released each month for cost accounting purposes. Such a scrap report serves best when it is analyzed daily to correct the cause of excessive losses while they are fresh in the foreman's mind.

All items scrapped because of foundry defects are charged against a foundry scrap clearing account which in turn is washed out when a credit memo is returned from the foundry covering items scrapped during a given period, generally one month. It is quite common for foundries to replace defective castings, but any labor expended up to the point where the defect is known is generally lost.

The salvage values of all items scrapped because of errors in the shop, errors caused by faulty information in drawings or specifications, damage or loss caused by assembly or testing, and damage from other undefined causes are charged against a salvage material for resale account. When the material is sold the account is credited for the amounts received from such sale.

The accounts in Figure 2 show that the accumulated standard costs of the items when scrapped were \$299.47 for the period involved. The castings replaced by the foundry provided a credit of \$16.19 while the actual scrap value of the material from the other parts was \$10.45. These two credits reduced the scrap loss to \$272.83. Thus the journal entries based on this scrap report are posted as follows:

1. Debit foundry scrap clearing account	\$ 16.19
2. Debit salvage material for resale account	10.45
3. Debit scrap loss	272.83
	<hr/>
4. Credit inventory	\$299.47

As the replaced material for item 1 and the money for item 2 comes in, these items are washed out leaving the inventory loss, due to scrap, of \$272.83.

Cooperation between cost accounting and production control can eliminate duplication, such as inventory records (see Chapter XIX), routing and operation sheets (see Chapter XI), material requisitions (see Chapters VII and XXIII), machine tool records (see Chapter XIV) and the fundamental information necessary for labor time accounting (see Chapter XXIII). Production control compiles, works with, and sometimes keeps records of this fundamental information. It can and should be made available to cost accounting or any other

group who can use it. The system of orders and returns can be designed to furnish complete production information to any interested group almost automatically at little additional cost.

QUESTIONS AND PROBLEMS

1. Design a set of forms to act as an operation sheet, labor ticket, material requisition, inventory control, and cost accounting record. This may be done with two forms.

2. Why is a scrap report desirable?

3. Can duplicate records maintained by two or more groups be justified as a matter of policy to insure a check on the accuracy of such records?

4. What should be the governing factors for deciding which group or groups should gather the data and maintain the records, and who should have access to the records?

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Chapters XVII through XXV are directly concerned with production planning and control.

CHAPTER XVII

COORDINATION OF SALES AND MANUFACTURING

The sales forecasting program of any company provides a solid foundation for good production control. Since it is necessary to plan for materials and plant capacity several months in advance, it is essential to have a projected sales program as a basis for such plans. Some concerns hesitate to predict sales too far in advance because they are subject to current conditions. But planning for the future does not mean that such plans must be rigid. As conditions change, those in charge of the planning groups must have enough flexibility to conform to the changes. Generally it is possible to make adjustments in the production schedules from two to six weeks ahead of the actual production program. If this flexibility is maintained in production control it is possible to follow current conditions quite closely.

If the sales forecasting function is not well developed or if it is almost absent, the scheduling of purchases for materials and plant capacity must be done on a hand-to-mouth basis. The demand for labor, the machine capacity, and materials may fluctuate violently owing to their dependence on current conditions, or the wild guesses of the purchasing and production departments may cause unbalanced inventories of raw or finished goods. Whenever sales forecasting is neglected in any company, one can be almost assured that the planning functions have also been neglected as a major factor in maintaining the plant's efficiency.

Sales forecasting is generally done by a statistical group working with either the sales organization or the general management. This type of forecasting may be used to ascertain the potential demand for a company's products according to seasonal or cyclical variations, or it may be used for the social and industrial aspect of providing a more continuous employment for the plant's employees.

Some emphasis has been placed recently on the desirability of stabilizing employment during the year. This should not be interpreted to mean that anyone should keep his labor force constant year after year. However, the policy of maintaining about the same num-

ber of workmen in any given year, even though sales fluctuate seasonally, does have certain advantages for some industries.

Production control in cooperation with intelligent sales forecasting can aid in promoting such a program by carefully arranging the manufacturing schedule to fit into the stabilization plan. At the present only a small percentage of companies have attempted to stabilize employment in their plants. Nevertheless there appears to be an increased demand from various sources for such studies.

The social aspect of a more stabilized production program will provide impetus to a more accurate method of sales forecasting. Statisticians are continually searching for better methods to predict sales potentials for various products. In this chapter the experience of several companies in widely diversified fields will be reviewed to demonstrate that sales forecasting can be done.

The most obvious reason for trying to coordinate sales and manufacturing is to balance the production and inventories systematically. Indirectly any plant doing a good job in this respect can give greater job security to its employees, can introduce new products, and can plan new developments when they are actually needed to step up business. Most manufacturers feel that better coordination would be desirable, but there is a wide difference of opinion on how to accomplish this. Some programs are so complicated and so many assumptions have to be made that the results are not accurate enough to warrant the trouble to get them.

Most industry today will agree that it has three responsibilities: to the customer, to the employee, and to the stockholder. When an industry assumes a dominant position in any community, some feel it should take on a fourth responsibility—to that community. When a plant employs a large number of people in a community the lack of stability in employment may affect not only the town but the immediate trade area also. Hence, stabilization of employment is often a social as well as an industrial problem.

The problem of stabilization of employment through periods of prosperity and depression commanded the attention of many people during the great depression which began in the 1930's. A number of schemes have been suggested and some tried, but little has been accomplished on the whole problem of stabilized industry. The main approach, so far, has been to spread the available amount of work by working fewer hours per week and by constructing public works during slack times.

There is another type of employment fluctuation which is the result of seasonal variations in demand. This problem of employment

change has been attacked quite successfully by a number of manufacturers. The Dennison Manufacturing Company, Eli Lilly Company, Procter and Gamble Company, Nunn-Bush Shoe Company, Geo. A. Hormel and Company, Eastman Kodak Company, and many others have attacked the problem of seasonal variations and have found workable solutions. Procter and Gamble have been guaranteeing forty-eight weeks of work per year since 1923. The Nunn-Bush Shoe Company started to stabilize their production in 1935 and have been guaranteeing fifty-two pay checks a year since that time.

Manufacturing plants may use special methods in the production and distribution of their products or in handling their personnel to control seasonal fluctuations in the business cycle.

Planned Production.¹ The most common method of eliminating seasonal loads on the factory is to accumulate stock during the slack season, thus keeping production levels fairly constant throughout the year. The Eastman Kodak, International Harvester, Procter and Gamble, Remington Rand, Otis Elevator, Hills Brothers, Walworth, Dennison Manufacturing, and American Radiator companies, among many others, are using this method to stabilize production.

Some companies reduced the number of seasonal items to a minimum so that stable products can be made during the slack seasons. The reclamation of waste accumulated during the busy seasons will help to keep some employees on during the slack season. At times when the industry is expanding, some of the factory force may be used for construction during slack times, but this practice is open to criticism because, unless the supervisors of factory construction are experienced in building, the cost of the buildings may be excessive.

Some industries in certain areas have cooperated with vendors in their mutual purchasing problems to enable others to produce on a stable basis. Such cooperation can have far-reaching results if effectively planned and carried out.

Planned Distribution. Seasonal fluctuations in production can be reduced by changing the policy of distributing the product to fit the need. Price reductions in off seasons can stimulate demand enough to reduce the severity of the seasonal demand for the product. More intensive advertising during slack times often accomplishes the same results as reducing the price. A combination of these two should be quite effective.

Some companies develop or release new uses for their products during slack seasons. They develop new products which do not have

¹ "Stabilization of Employment and Income," M. B. Folsom, Treasurer, Eastman Kodak Company, *The Conference Board Management Record*, Vol. 1, No. 2

their seasonal peaks at the same time as do the older products. This is an excellent way to stabilize, particularly if the new products can be made without buying new machinery. When new buildings and new machinery are necessary to make a new seasonal product which will dovetail with an older product, it sometimes will stabilize employment but it may reduce the effective use of capital.

Examples of companies which have diversified their products in this manner are Welch Grape Juice, International Harvester Company, Graton and Knight Company, Eastman Kodak, and the rubber companies which have made large stocks of shoes, overshoes, and raincoats to keep production up during the slack season. By offering special discounts to dealers if they purchase their stocks during slack seasons, the demand is increased during slack times. However, this last method may not help the movement of more goods over the year unless the dealer passes some or all of the reduction on to the consumer.

There are thousands of manufacturers who alter distribution methods in an attempt to change buying habits, but not all adopt a planned procedure to stabilize production in the plant. Nunn-Bush Shoe Company, Geo. A. Hormel and Company, Hills Brothers, General Electric Company, Westinghouse Electric Corporation, and many others are controlling their seasonal fluctuations in some measure by planning changes in the method of distribution.

Only the control of seasonal fluctuations will be discussed in this chapter. A. H. Robinson,² in his paper delivered before the Seventh International Management Congress, makes the statement, "Any successful method of seasonal control will of necessity provide the machinery which will make more effective the first steps in cyclical control." Stabilization is easier for some industries than others, but when we look at the list of concerns which have accomplished a considerable measure of stability during trying times we must conclude it can be done.

Some companies provide an incentive to stabilize by guaranteeing their employees a definite amount of work per year. The Procter and Gamble Company is one of the best known in this field. Guaranteed employment does not stabilize in itself. If nothing outside of issuing a guarantee were done, the guarantee as well as the industry would necessarily break down. Unless a plan for stabilization is al-

² *Basic Factors Governing the Effective Coordination of Manufacture with Other Operating Activities of the Business*, A. H. Robinson, Assistant Treasurer, Eastman Kodak Company, 1938.

ready in action and working well, it is not wise to give any guarantee of work beyond immediate orders in the plant.

Planned Personnel Policies. Another method of stabilization shifts employees from one department to another where loads vary in different seasons. Griggs Cooper, a large wholesale grocery manufacturing concern, shifts employees from the department making winter cakes and cookies to the one making special cakes and cookies sold more generally in the summer. A large olive-packing department is busy in late winter through early summer. Some of the girls from the olive department are then transferred to the pancake syrup, bluing, and candy departments which are more active in early winter. Since division of labor is so extensively used in many industries, the problem of moving from one department to another is not at all serious if only a little time is allowed for training. Surveys³ made in industry have shown that men do move from one job to another with remarkable freedom.

More and more employees are now asked to take their vacations during the slack seasons. The popularity of winter vacations is increasing because the southern states are now prepared to take care of winter vacationists. In addition, the two-day week-end which is so common in industry allows recreation time at near-by places during the summer so that the need for summer vacations seems to be decreasing.

A method commonly used to achieve stabilization involves the accumulation of stocks during the slack season in anticipation of sales peaks to come later. Mr. Robinson's⁴ paper deals largely with the Kodak plant and the scheme used for certain products. This company began about 1915 its first experiments in accumulation of stocks during the slack season as a means of stabilizing roll film production. This principle of stabilizing production has now been extended to practically all the manufacturing operations in the Rochester, New York, plants.

The method at the Kodak plants involves three major steps: "sales forecast with its measurement of seasonal tendencies; determination of production levels; and control of stock levels."

Sales forecasting is an important step in stabilizing an industry. Methods have been developed which, by the use of surveys and anal-

³ *Job Analysis of Manufacturing Plants in Minnesota*, Charles A. Koepke, University of Minnesota Press, 1934.

⁴ *Basic Factors Governing the Effective Coordination of Manufacture with Other Operating Activities of the Business*, A. H. Robinson, Assistant Treasurer, Eastman Kodak Company, 1938.

ysis of factual data, have been helpful in predicting the market for a new product. This type of information can only point to a possible market and the projected figures are not always realized. Henry S. Dennison, President of the Dennison Manufacturing Company, reports: ⁵

The business weather is, at any given moment, the result of a confusing combination of forces. . . . Exactness in prediction can hardly be expected as yet though careful forecasting should have chances in its favor over random guessing, just as weather forecasting has.

In 500 forecasts of general prices, just over one-half were found correct, just over one-quarter were incorrect and about one-fifth negative, that is neither harmful nor helpful in their results. The ratio of helpful to injurious predictions was 18 to 10.

He concludes his discussion on business forecasting thus:

However specific results in its chosen field may be judged, forecasting must be credited with having done a considerable share toward developing a desire in the American business manager to look farther and farther ahead, a growing faith in the possibilities of doing so, and finally, a habit of mind which has shown its influence not merely in forecasting for the guidance of general management but in departmental budgeting, production planning, far-sighted research, and longer range planning of capital expenditures.

This discussion was written about twenty years ago and considerable progress has been made in sales forecasting since that time. The difficulties of forecasting sales come largely from inaccurate knowledge of all the facts and their interrelationships. Large industries have staffs of statisticians constantly at work to discover better and more reliable relationships between facts which can be readily obtained. Sometimes certain potential statistics and historical data are not readily available. If these data concern consumers' habits it may entail considerable time and expense to collect them. If other plants in an industry are involved in gathering the facts, competitive spirit may make them hard to get. After the facts are known, they must be analyzed and later synthesized into new relationships which are tested in the light of experience. These relationships vary from one business to another, and each should be tested for the particular type of product which is to have a sales forecast made. The degree to which a company enjoys a monopoly in any product will alter the

⁵ *Recent Economic Changes in the United States*, McGraw-Hill Book Co., 1929, Vol. II, pp. 505-507.

response the company can expect from the consumer. The type of product, that is, whether it is food, clothing, luxuries, household equipment, or factory machinery and other producers' goods, will materially change the forecasting picture because of the different interrelationships of facts.

Long-range forecasting even with old, established products is not a reliable device for many types of manufacturers. The vicissitudes of business prevent long-range planning except for certain companies which supply a product or service which promises to be marketable

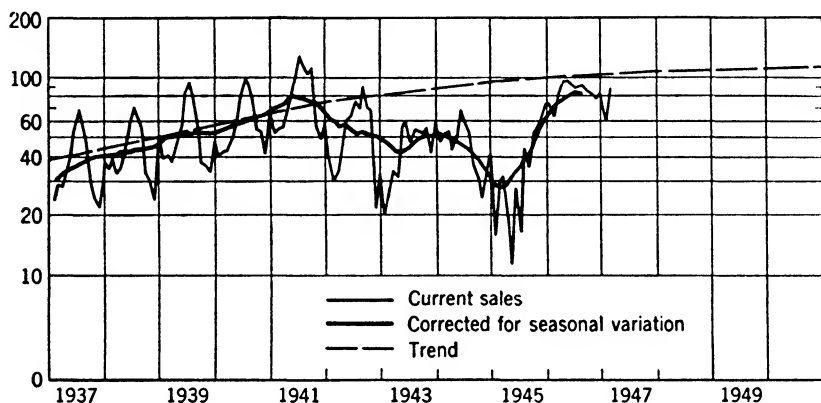


FIGURE 1. Typical sales graph.

for some time to come. The American public has been a meat-eating nation for a long time and probably will continue unless an unforeseen substitute steals its market. The meat packers along with the telephone and public utility concerns can and do make long-range forecasts. Telephone planning in some phases such as buildings will look ahead ten years or more. Other organizations which can do long-term planning seldom try to forecast more than five years.

Forecasting for Sales. For products which have been on the market for years, it is possible to predict sales trends graphically. Figure 1 shows a graph of the sales of product B of the Eastman Kodak Company⁶ from 1937 into 1947. The widely fluctuating light line shown on Figure 1 indicates the monthly sales. The heavy black line shows the trend much better because the seasonal variation has been eliminated. Though the heavy black line trend obviously reflects the variations of the general business cycle, it also shows the long-view trend. The dashed line is a calculated curve to measure the secular

⁶ "Stabilization of Employment and Income," M. B. Folsom, Treasurer, Eastman Kodak Company, *The Conference Board Management Record*, Vol. 1, No. 2.

trend, and these three curves in Figure 1 illustrate a rather typical pattern found in many seasonal products. The data are plotted on semilogarithmic paper to simplify the curves and to indicate the rate of change directly.

Any good textbook⁷ on business statistics discusses the techniques of trend determination and methods to eliminate the effect of seasonal variations. This kind of work employs both mathematical and graphical means and the method used should be one which will give the necessary accuracy with the minimum cost. Graphical methods, in which regular ship curves are used to draw the trend lines, are usually satisfactory for most purposes.

Historical trends, such as shown in Figure 1, help in forming future policy. Unless something of a radical nature has occurred in the distribution or use of a product, the growth curve tends to follow a rather definite pattern. If a plant's technical staff, sales department, and statistical experts are in touch with each particular product's market, they can forecast to a considerable degree what the demand for it will be. Any new uses, which the customer or the technical staff may discover for the product, may affect the trend lines and help to explain sudden increases in demand. When such new uses are carefully analyzed to see whether they satisfy an established need or just an incidental fad, the upturn in the trend can be studied for its true significance.

Likewise, substitutes, stronger than normal competition from an inspired producer, or a decline in the demand created by natural economic changes, may cause a drop in the trend line of a product. Any unnatural rise or fall in the sales trend should be analyzed immediately to find the fundamental reason. Managements forewarned by such information are seldom caught with either too much or too little inventory as economic cycles and changes occur.

It is important to have cooperation in the sales, advertising, production, and product-developing divisions to make good sales forecasts. To be of greatest value for stabilization purposes, it is desirable to forecast at least one year in advance. Seasonal variations are often a function of the calendar year and thus tend to repeat in yearly cycles.

After considering all factors which may affect the sales trend (Figure 1), the projected line is entered on the chart. The forecasted demand is then read off the chart and the proper seasonal adjustments are made for each month. The Eastman Kodak Company uses a

⁷ See bibliography at end of this chapter.

thirteen-period calendar so that the total sales for the year are the sum of the adjusted sales figures for each period.

The normal seasonal variations of sales, production, and stock for product B in each of the thirteen periods is shown in Figure 2. The heavy solid line shows the normal sales demand for product B during each period. The sales demand for each period is expressed as a percentage of the yearly sales demand. Note that the normal demand

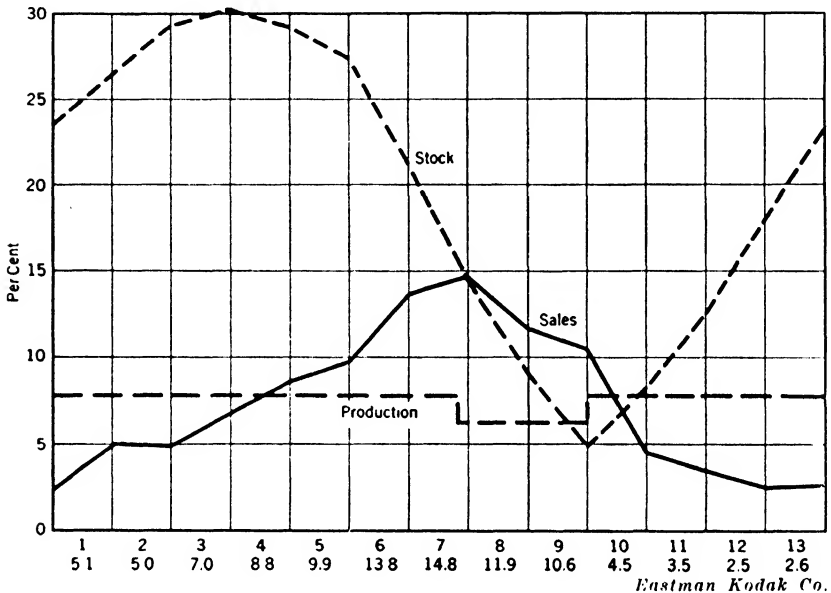


FIGURE 2. Normal seasonal variation in sales, production, and stock.

during the fifth period is about 10 per cent whereas during the thirteenth period it is only about $2\frac{1}{2}$ per cent.

Sales Forecast Sets Production and Stock Control. The sales forecast curve makes it possible to plan a production and stock control which are shown as a dashed and dotted heavy line respectively in Figure 2. The dip in the otherwise straight production line during the eighth and ninth periods is to allow for vacations. The percentage of the yearly demand which is made each period would be roughly $\frac{100}{13} = 7.7$ per cent but owing to less production during the vacation periods this percentage would be somewhat higher during the remaining eleven periods.

The amount of finished stock, in percentage of the yearly demand, which should be on hand during each period is now determined. The

minimum stock exists when the sales rate drops below the production rate, for then the stocks begin to accumulate again. The stocks continue to accumulate until a maximum stock is reached when sales exceed production.

At the time the minimum stock occurs the calculations for the next year's stock are made. The stock is allowed to drop to the amount which must be carried at this low point to insure adequate service to customers. The stocks for each of the succeeding periods are deter-

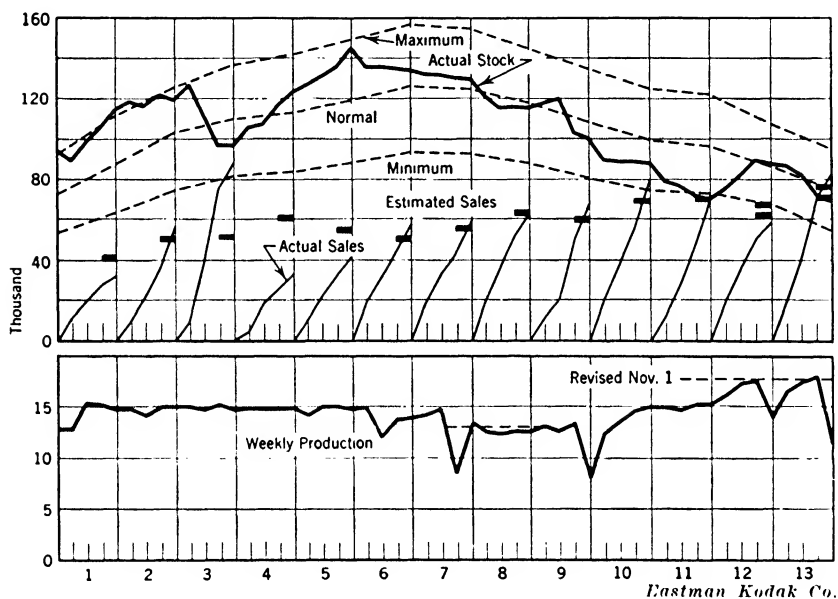


FIGURE 3. Actual data on production, sales, and stock for product E.

mined by adding production and subtracting sales for each of the periods in order, beginning with the minimum. Thus, with a minimum of 5 per cent stock at the ninth period, plus the normal production of about 8 per cent stock at the ninth period, minus the sales of about $4\frac{1}{2}$ per cent, the stock level at the end of the tenth period would be $8\frac{1}{2}$ per cent. For product B the stock reaches a maximum of about 30 per cent of the year's supply at the end of the third period.

In addition to seasonal fluctuations, there are apt to be wide and unpredictable variations of the sales from week to week, and from period to period. True stabilization must, therefore, provide some means of producing steadily in spite of both weekly and seasonal fluctuations. The stock must absorb the shocks, for an important

function of a stock of goods, either finished or in process of manufacture, is to serve as a supply cushion to meet variations in requirements. This function of stock is often overlooked. Stock-keepers frequently consider a definite stock figure as normal, and place orders to maintain this fixed level. The stock, in this kind of control, is not serving as a cushion to absorb fluctuations, but is serving only as a place of turnover. In actual practice, then, this may result in sales fluctuations being passed on to production in an exaggerated manner. Hence, the reason for introducing minimum and maximum stock levels at such distances from the normal is to absorb the ordinary weekly and period sales fluctuations.

Figure 3 is taken from the production-control records of one of Eastman's important products. The production line for the two levels is indicated in the lower part as the light dashed line, and the actual production each week is plotted in the solid line. The normal stock line in the upper part is calculated in the same manner as the stock in Figure 2. It does not have the wide swings, as was the case in the previous chart, because the seasonal fluctuations in sales are much less pronounced. The maximum and minimum stock lines are shown. These two lines are placed at approximately 25% above and below the normal line. This 25% allowance works out quite satisfactorily for most products, although it may vary according to the product or its manufacturing conditions. These maximum and minimum lines may be considered as the key to the effectiveness of this stabilization program.

By way of summary, therefore, the success of production stabilization is the result of, first, accurate sales forecasts; second, the absorption of the seasonal fluctuations by changing the normal stock level throughout the year; and third, the absorption of the weekly and period fluctuations through the establishment of maximum and minimum stock limits.

The application of the principles described must be specific for each product. Some products, such as high-grade cameras, may require six months in the process of manufacture, while other products may take only a few days or a week to complete. Some classes of goods are in continuous production, while others are manufactured in job lots.

In all cases it is highly desirable that a production control method should be established for each principal producing department in total, as well as for each product. Individual products may fluctuate, but so long as the total is kept at a constant figure, stabilized production is accomplished.

The Eastman production planning program is in operation at all of the company's plants. The program is constantly being extended in scope as required by the growth of the business.

Results of the Eastman Plan. What have been the results? Figure 4 shows the seasonal variation in sales, production and employment for the entire Kodak Park Plant, with about 10,700 employees. The indexes cover the three years 1934, 1935, and 1936, and are adjusted only to take care of the growth element during that period. The sales index is based on the dollar value of sales for all products manufactured at this plant. The production index

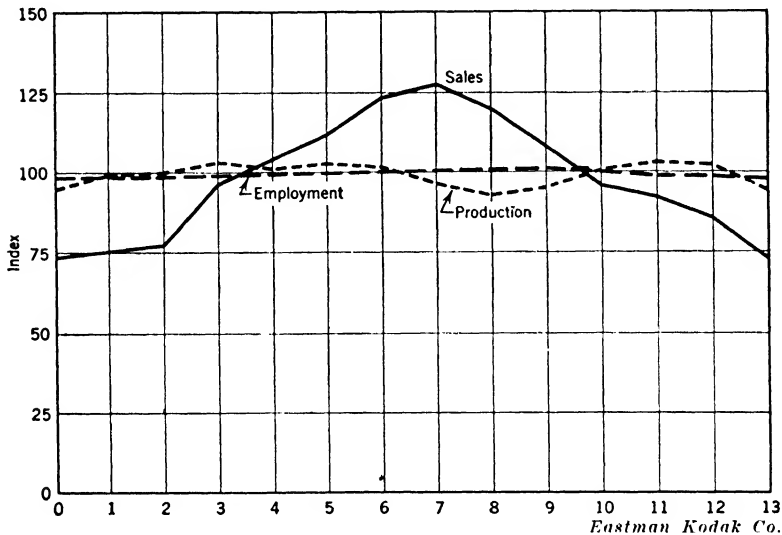


FIGURE 4. Seasonal indexes for Kodak Park Plant. Actual data on sales, production, and employment, based on three years: 1934, 1935, 1936. Average for year = 100.

is based upon man hours worked, and the employment index is based on the number of employees on the payroll. The low point in the production index is in mid summer months when the vacation allowance is greatest. The thirteenth period is also a low point but includes holidays and some shut downs. In spite of the variation in production rates which may be due to vacations, holidays, illness, etc., the number of employees on the payrolls remained quite constant with maximum seasonal fluctuations in any one month of approximately 1% above or below the average as compared with sales fluctuations of about 27%.

The labor turnover rate for all causes for three years 1935-1937 was 8% or about one-fifth of the national average, while the lay-off represented less than 1% of the number of employees.*

* "Stabilization of Employment and Income," by M. B. Folsom, Treasurer, Eastman Kodak Company, *The Conference Board Management Record*, Vol. 1, No. 2.

Nunn-Bush Plan. The Nunn-Bush Shoe Company ⁹ is another plant whose management has done some original thinking to stabilize production in a difficult field. The company is located in Milwaukee, Wisconsin, and has been making fine shoes since 1912. The plant is one of three leading manufacturers of high-grade men's shoes in the United States. The highest-grade shoes are produced in the Milwaukee plant, while a cheaper shoe has been made since 1934 in Edgerton, Wisconsin. The Milwaukee plant employs about 850 people and the Edgerton factory has about 300 people. Except for small deficits in 1931 and 1932 the Nunn-Bush Company has an excellent earnings record. The original plant started in a small way with a capitalization of only \$90,000. After a few years the plant grew large enough to cause some thought to be given to a forward-looking labor policy which would guard against possible mishandling of the employees.

To bring the matter to a head, the executives called in the original employees and asked them to form a society or union. The action was entirely voluntary. It was not precipitated by any acute situations but was based on a carefully devised plan to secure better cooperation and morale in the factory.

To indicate sincerity on the part of the management, they signed away the right to discharge arbitrarily any workmen. Dismissal would be made only through agreement with the workers' elected committee.

It is interesting to note Mr. Nunn's philosophy on prerogatives of management. He says, "Many business heads feel that to dictate policy is a prerogative of management." But such dictation in his opinion is poor management. Only the weak submit to dictation and the weak have a way of growing strong. Alternate periods of strength between management and labor engender alternate periods of power dictation where each may prosper or suffer as he happens to be up or down.

The Nunn-Bush Company does not feel it has made any sacrifice of necessary management power. It has made it obligatory for its executives to be fair and just in their actions. If a man is to be discharged, the foreman knows that snap judgment or hasty action is going to be checked by the union. If the union's committee decides the discharge is not justified, it is assumed that the committee is right and the executives are wrong.

As mutual confidence grew, the greater was the cooperation between the union and management in affairs of management. Over a period

⁹ *The Nunn-Bush Plan*, booklet published by the company, October 1938.

of more than twenty years they have developed methods of cooperating on the discharge of old employees when necessary, the hiring of new ones, working hours, number of working days per week, amount of wages to be paid, and other things which come up from time to time. All problems are settled by mutual agreement or, if that fails, by outside disinterested arbitration.

Mr. Nunn's comment on the result of such cooperation is worth noting. "It is my belief that the disposition of workmen to react favorably to a fair proposition is much more pronounced than when dealing with the average business man. I have had many unfortunate experiences dealing with business men who, with lawyers at their elbows, seemed disposed to acquire not what was fair but what they could get."

With such a long-standing history of mutual understanding and cooperation in the Nunn-Bush plant, it is only natural to expect further experimentation and improvement looking towards better economic relationships between labor and its management. Up to 1935 factory workers had been paid by the hour whereas office employees and executives were paid a monthly salary. An analysis of organizations almost anywhere discloses that invariably the office and executive personnel is loyal and faithful to a business. The security in their jobs coupled with yearly salaries have made them feel a part of the organization. Factory labor on the other hand is the first to be separated from the payroll when business declines. Under such conditions labor is likely to feel responsible only on a day-to-day basis.

To find a method of paying annual salaries to factory workers instead of a more or less variable weekly wage was the next problem to be worked out. In the first place, it is the annual income rather than the wage per hour which counts in any evaluation of wages, but one of the main advantages of the hourly wage is its flexibility during economic changes. Therefore, any annual wage plan for factory workers would be much better if it could have this same flexibility.

In seeking a solution, the Nunn-Bush Shoe Company discovered a fundamental fact which may have far-reaching industrial significance. It found surprisingly enough that the percentage of the sales income dollar going to labor over a long period of time was almost constant.

Since few plants, even in the same industry, have comparable percentages of gross income paid to labor, no good purpose would be served by disclosing the percentage paid in the Nunn-Bush plant. The percentage would vary with the type of business, the number and type of workers, and the departments included in the plan. It can be said, however, that, when the percentages paid in the past years were

being analyzed, the spread was only 2 per cent from the highest to the lowest. The analysis showed it was necessary to exclude several departments at first to get this exceptionally fine agreement. The sole-cutting department was excluded because, depending on market conditions, the company had not always cut its own soles. The heel and counter department and employees such as foremen, janitors, and maintenance men, along with stockroom, shipping, and office men were also excluded at first. Later the sole department together with the other excluded full-time employees were analyzed and placed in separate groups to be paid in similar fashion from a percentage of the gross income. There is a little-known economic law which has enabled the workers in a plant to receive just so much of each dollar regardless of how many dollars came in as gross receipts.

After the full significance of the constant percentage spent for wages was realized, it was deemed practical and just to alter the wage-payment system and to guarantee employees fifty-two pay checks per year regardless of business conditions or factory shutdowns. In brief, the plan involves the payment of the set percentage of the gross receipts into a wage fund. Since the exact amount of the individual salaries under this method cannot be determined until the end of the year, a system of drawing accounts for each employee is set up. These drawing accounts are based on the estimated volume of business and are adjusted up or down periodically as business exceeds or fails to meet estimates.

Because sudden increases in production may require additional personnel it was necessary to have a provision for adding men to the payroll. If these men were placed on the annual salary plan and guaranteed fifty-two pay checks the salary fund would be spread too thin in times of deflation. Consequently, new employees come in on a "B" basis for two years before participation in the annual salary. After serving two years, new employees can still be laid off until such time when, according to seniority, they are accepted by management and *the workers* already in class A as members of the permanent force. About 5 per cent of the Milwaukee production employees were class B workers in 1937 and about 11 per cent in April 1938; in January 1940, the class B workers had been reduced again to about 7 per cent.

Each month the workers' executive committee is furnished figures showing the economic status of the business as it concerns the distribution of the salary funds. Adjustments are made from time to time during the contract period. At the end of the fiscal period the workers employ a certified public accountant to verify all figures which have been furnished by the management.

Management at the Nunn-Bush plant has had to become more efficient as a result of paying its employees an annual salary. Factory production has been stabilized, and labor turnover has been reduced to very low levels. The plan has been through an increase in prices and also a severe decline in 1937. Their workers have taken both in stride with exceptional cooperation.

The plan has acted as an automatic governor which tends to keep the business from swinging quite so high in good times or so low in poor times. Since labor cost is a percentage of each dollar taken in rather than a fixed wage load, the company in cooperation with the workers can make price revisions downwards in poor times. This tends to sell more shoes. A rise in the price of their shoes, providing it does not decrease the sales, automatically raises employees' earnings. When a decrease in prices is made, sales tend to be maintained and the employees' incomes are maintained.

For example, if the price at the factory is reduced on a pair of shoes from \$6 to \$5, the management knows in advance that the labor cost would also automatically be reduced, say 20 cents. If the raw materials are also falling at the same time, which is often true in a falling market, a price reduction in the wholesale cost of shoes is easier to make than in the normal wage situation. The weekly drawing accounts of the workmen are reduced only if the dollar sales volume is reduced. If the price cut succeeded in maintaining dollar sales, the workmen would continue to be paid the same amount.

Thus the Nunn-Bush plan makes it easy to reduce wages in times of stress and just as easy to increase wages as business improves.

Since no class A workers are laid off the plan may encourage technological advance in machinery. Any new machines or methods which increase production, reduce cost, or raise the quality of the products may increase the dollar sales volume without increasing the number of employees. Such improvements are naturally not opposed by the Nunn-Bush employees because they increase their yearly earnings.

This wage-payment plan is in no way a profit-sharing plan. The workers get the same percentage of the gross income whether the company makes a profit or not.

The percentage of value going to labor may be a question with all the elements of controversy which now beset the amount of hourly wages. Mr. Nunn, however, in his experience with this new method of payment of wages, declares that the frequent discussions and analysis of company operations and expenditures and the analysis of the disposition of the company's gross income dollar has educated the worker. Workers now know that the capital of a business cannot pay

the salaries and that income is based on the number of dollars of gross income which in turn depends on the number of shoes produced.

It should be noted that one of the usual results of a good employment stabilization plan—a smaller volume of employment—seems to have occurred here also. In 1939 about fifty fewer employees were on the payroll than in 1935. However, in 1939 about 11 per cent more shoes were produced. This difference in the number of employees was due to natural causes; no one was arbitrarily removed from the class A list. A rough comparison of the average weekly earnings of the Nunn-Bush employees with the rest of the shoe industry is shown ¹⁰ in Table 1.

The figures in this table do not tell the complete story because few shoe firms operate throughout the year. The annual earnings for the industry as a whole would not be fifty-two times the average weekly wage as in the Nunn-Bush plant.

TABLE 1
AVERAGE WEEKLY EARNINGS

<i>Year</i>	<i>Nunn-Bush</i>	<i>65 Shoe Plants</i>
1934-35	\$19.38	\$20.61
1935 (six mo.)	21.35	20.93
1936	24.23	20.89
1937	26.63	20.89
1938	23.08	17.76
1939	24.42	18.74

The new basis for paying an annual income to factory workers which has been in use for thirteen years has been a stabilizing influence in itself. This was the main purpose of outlining its operation in this chapter. Moreover, such a plan will stimulate study to find methods for further stabilization of employment for factory workers. Additional incentive is automatically provided in a majority of states by the reduction in payroll percentages for unemployment compensation for those who meet certain requirements.

The standard unemployment compensation tax rate in Wisconsin is 2.7 per cent on the defined payroll. Variations in the tax rate are allowed ranging from 4 per cent down to zero per cent. The maximum rate is used where the company's compensation reserve fund has been overdrawn. The majority of states operate under a similar system of variable rates. In Minnesota the variation ranges from 0.5 per cent to 3.25 per cent of the defined payroll. In 1943 the rate was reduced

¹⁰ "Employment Stabilization," Charles A. Myers, *Personnel—American Management Association*, Vol. 17, No. 1.

from 3.5 to 2.75 per cent for the firms having bad records showing unemployment. This may be increased for the bad risks if the state unemployment fund is reduced to a certain minimum.

Production Control. Any annual wage plan or a plan for guaranteeing a certain number of weeks of work per year needs something additional to make these plans work. Nunn-Bush have a plan in use which has been successful in stabilizing its production of shoes and thereby making it possible to pay the annual salaries.

Most people fail to realize the large variety of shoes which must be manufactured and carried in stock to be able to satisfy customers' demands. Nunn-Bush produces sizes 5 to 12 by one-half size increments. This gives fifteen sizes which are all produced in nine widths (AAA to D); $9 \times 15 = 135$ different sizes for every model of shoe, every color of leather, and different leathers or combination of leathers. Consequently, to carry one pair of shoes of each size and width in any one style or model would require 135 pairs to be in stock. The company produces about 150 different models or styles of shoes at all times. When the sales records show a decline in volume of any model to a certain point, a new design is introduced to take its place. About 77 per cent of the total sales volume is derived from 30 of the 150 models.

The company maintains three warehouses, the largest one at Milwaukee, one in New York, and one in San Francisco. Warehouse storage and production facilities have been so arranged that the average pair of shoes remains in process and in the warehouse about thirty-five working days. Process time alone has been about eleven working days. Since the plant is on a five-day week, the turnover of shoes in the combined cycle of production and warehousing is between seven and eight times per year. Shoes sold directly to dealers from the factory have a process turnover of about twenty-two times per year. Consequently, the dealer who does not foresee his needs is charged more for shoes ordered out of warehouse stock than he is if they are ordered far enough ahead to be planned for in the factory.

To get the proper retail outlets in some cities the Nunn-Bush Company maintains 115 retail stores or departments in clothing stores which account for about 35 per cent of the total business. These are set up as a method of obtaining nation-wide sales in areas where the good stores already have a high-grade line of shoes. The turnover in these retail outlets is about two times per year.

The company in the past has owned about 250,000 pairs of shoes in process, warehouse, and retail outlets. This, however, is being gradually reduced as inventories are controlled better. Towards the close of 1937, when business dropped off rapidly, the inventory built up

twelve days over the thirty-five-day ideal previously used. The factory force had been expanded to keep up with the current demand, and stocks built up rapidly when sales suddenly dropped. Under the spur of reduced prices to the consumer, the company found sales increased enough to reduce the inventory. From October 31, 1938, to the same date in 1939, the inventory had been reduced 40,000 pairs from a point which had been thought necessary in previous years. By continuation of the same policy, which was learned in the 1937 decrease in business, the company expects to reduce the inventory another 27,000 pairs. This will mean a total reduction of 67,000 pairs from the supposed normal number which was carried in 1938. In other words this 67,000 pairs can be used now, if necessary, as an added cushion for warehouse expansion in slack times and the company will not be in any worse financial state than it was in 1938 when its inventories were considered down to a minimum.

The amount of stock to be carried is set by the sales department. It must be large enough to care for customer demand, but if it is too large the carrying charges react against the sales department. To a large extent, only the stable lines are manufactured for warehouse stock. As an incentive for retail buyers to make their purchases far enough in advance to have the shoes made to order, the retail buyers are charged an extra 2 per cent if their shoes must be taken from warehouse stock.

The planned production for any week is based on the number of shoes sold for that week plus the number of shoes which must be made to keep stocks up to normal. This total number of shoes for that week is then added to the total number of shoes actually produced during the last fifty-one weeks. This production for the year, ending one week hence, is then divided by the number of working days per year (247) to get the daily production necessary for the next week. By this method the production is definitely tied to the demand which has existed for the last year.

Stable lines of shoes are used to fill in production valleys when sales are not up to production possibilities. Sales are made every working day of the year, but there are spring and fall seasonal peaks. The seasonal trends are known and can be fairly well predicted. The secular trends are more difficult and the Nunn-Bush Company is learning something about them by experience and experimentation. When sales drop below the normal for any period, the natural labor turnover in the production department is allowed to operate to reduce the working force. That is, deaths, marriages, and other causes of people leaving the factory gradually reduce the number of class A employees.

This plan tends to be the automatic governor previously mentioned. If business is increasing the factory backs up the load slowly while the warehouse absorbs the shock. On the other hand when business declines the factory production declines slowly and the warehouse absorbs the surplus.

Although in times of severe downward adjustment, some factory workers may work less than five days per week, the plant nevertheless attempts to produce shoes every working day. It is possible to give better customer service with less warehouse stock if shoes are produced every day rather than for, say, only three days per week. Through experience the company has found that it requires about 60 dozen pairs of any model in process and stock during the seven-week (thirty-five working days) period to serve properly customer demands. The process time requires about two weeks to send the material through the plant. To give the same service to the customer if the plant is run only three days per week the 60 dozen would have to be increased to $\frac{5}{3} \times 60 = 100$ dozen for process and stock.

The plan has stabilized employment enough to place the company on the preferred list in Wisconsin. There are no payroll deductions for unemployment compensation because the reserve fund is as large as the state demands.

The employees seem to like the plan. It permits them to manage their personal affairs in an orderly fashion. They do not have to worry about unexpected layoffs and complete cessation of wages. Annual wages for the factory workers have increased under the new plan and the factory has gained better, more dependable employees as the natural result.

The Hormel Plan. Although the packing industry has the highest layoff rate of any major industry, Geo. A. Hormel and Company ¹¹ of Austin, Minnesota, provided continuous employment for 98.1 per cent of its employees in 1939. In 1929 less than half of the Hormel employees were employed at the packing plant the year round.

Both the demand for the finished products from a packing plant and the flow of livestock to the plant are highly variable from day to day and month to month, and even, year to year. The daily flow, influenced by weather and market prices, varies from practically nothing to four times the annual daily average. The peak month may see two or three times as many hogs arrive, as the slackest month.

¹¹ "Stabilization Plan Guarantees 52 Pay Checks Yearly," by E. P. Schmidt, *Northern Automotive Journal*, June 1940.

In the old days, when livestock arrivals were few, there would be little work, and, of course, little pay. One could not blame the employees for trying to make the work last as long as possible. Under the new plan, every department has its tonnage budget. For example, the hog killing department may have a budget of 950,000 hogs. Enough people are assigned to this department to take care of peak volume in a 53-hour working week. This company is exempted from the time and a half requirements of the Wages and Hours Act by qualifying under Section 7 (b) (2). This provides that any employer who agrees to put some or all employees on some annual wage basis and not work them in excess of 2,000 hours per year may work them up to 56 hours in any one week and 12 hours in any one day without the penalty of time and a half; however, he must have a collective bargaining agreement with a union which has been certified by the National Labor Relations Board. This gives a sensible flexibility and yet places an annual "ceiling" on the number of hours. If more hogs arrive than the annual budget calls for as was the case in 1939, the employees in that department receive a proportionate year-end bonus for excess hogs put through the mill.

In very slack periods, the employees, or at least some of them, may not need to show up. Nevertheless, they draw their standard weekly pay check. If there are only a few hundred hogs in the pen, the employees instead of watching the clock and trying to make the work last, know that as soon as they have finished the day's work, they can go home, or go fishing, boating, or engage in any kind of leisure that they choose. Thus, during the slack period the employees are, in effect, "overpaid" but during peak periods they repay this "loan" with extra work above the normal work-week. In many departments, because clock-watching is abolished, the company found it could handle increased yearly volume, when business expanded, without increased plant, thus reducing overhead.

An "extra gang" of several hundred men is maintained. The members of this group have no permanent assignments. Rather, they are shifted from department to department. They may be loading hides one day, helping in the dry sausage department on another day, etc. As openings occur in the regular department, men are shifted on a seniority and merit basis to permanent assignments.

Mr. Hormel has felt for a long time that the usual wage-payment plans are fundamentally wrong. They tend to cause the men and management to form into opposing antagonistic groups. He feels that the method of determining compensation in the older wage-payment plans tends to divide the management and employees. He has devised and used a new plan which works as follows:

Suppose net sales for the year have been \$50 millions and the cost of livestock, fuel, containers, maintenance, any fixed charges and a few other items have been \$45 millions. This leaves a balance of \$5 million for stockholders and employees. Of this remaining \$5 millions the employees have been getting about 80% for doing the work, and the stockholders about 20% for putting up the money to finance the enterprise, as shown in the accompanying schedule:

Net sales	\$50,000,000
Cost of livestock, fuel, containers, etc.	45,000,000
	<hr/>
Joint earnings for wages and common stockholders	\$ 5,000,000

There are only two ways of enlarging the \$5 million figure: (1) more sales, that is, enlarging the first figure above, (2) reducing the second figure above by eliminating waste, etc. The employees get 80% of the balance left (\$4 million in this illustration) after deducting the second item from net sales. This is not just another profit-sharing plan; it goes deeper.

In short, under the new joint-earnings plan every additional dollar of sales means a few pennies extra for the employees and a fraction of a penny for the stockholders. Meat is cut more carefully to prevent grade 1 meat becoming grade 2 at a lower price. Livestock is more carefully handled in the stockyards and killing floors to prevent bruises. Every time hot water running to waste or electric lights burning uselessly are turned off, the employees and the management share in the saving. Employees have a direct and immediate interest in efficient operation. Employees can see now that the money which pays their wages does not come out of the pockets of the management but out of the productivity of the enterprise. If prices improve or volume increases, the employees do not have to wait until someone in the organization gets around to thinking of raising the weekly pay checks; rather, the employees benefit automatically. Also, it helps the employees to see that they are working for the consumer and not for the business. It is the consumer's dollar which pays their wages.

The guaranteed wage may become to labor of today what the eight-hour day was some years ago. Professor Joseph Snider has written a book ¹² concerning the theory and practice of guaranteeing work and wages. He feels that no company should guarantee more than it can consistently give nor less than the employees feel is worth while. The

¹² *The Guarantee of Work and Wages*, Division of Research, Harvard Business School, 1947.

guarantee should contain an escape clause if future conditions cause unbearable financial strain.

If management applies ingenuity and brains to the problem of stabilization of employment and uses the experiences of successful plans now in operation, real progress can be made. When and if such plans are contemplated in any industry, production control will be asked to supply a large share of the fundamental information to make any plan work.

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CHAPTER XVIII

PLANNING FOR THE PRODUCTION PROGRAM

The engineering portion of the preparation for production requires a complete analysis of the whole production process from beginning to end. This preparation involves techniques for planning each step of the manufacturing program to avoid difficulties and disappointments after the job is actually in production.

Planning Is Necessary. The factory personnel, regardless of its type of organization, must control the flow of work through the productive processes. The old line organization, where the superintendent, foremen, and workmen were held responsible for manufacturing the product, constituted the simplest form of factory control, but it left much to be desired. The attention given to a particular order when the shop was busy was in proportion to the amount of pressure brought by the customer. Most of the orders under this system became "rush" and yet little progress was made in getting the majority of orders finished on the promised dates.

Today, all well-organized shops realize that centralized planning of their jobs is necessary. No work is done by such planners except that which must be done by someone in the factory. Centralization simply may mean that each portion of the planning is done in advance by specialists, instead of by mechanics and foremen trying to make up a plan as the job progresses. Everyone knows that members of a brass band must have a musical score either before them or memorized if the group attempts to play difficult compositions. Trying to manufacture a complicated product under the old line plant organization can be likened to an orchestra in which each musician makes up his tune as he plays with the group. The result in both is chaos and discord which can be straightened out only by someone who organizes a score or plan for producing harmony.

PLANNING FOR THE PRODUCTION PROGRAM

The following outline shows a logical sequence for planning the several steps involved in developing and producing most products.

1. The need for basic planning for new products.
 - 1.1 The complex nature of many new products requires advance thinking instead of improvisation as the development program progresses.
 - 1.11 The services of many people are necessary at different levels of competency and their work usually must follow a certain sequence to conserve time and effort.
 - 1.12 As a program develops from design to finished product, there are many points of decision which have to be coordinated, disseminated, and executed.
 - 1.121 Over-all planning by competent groups is necessary to gather the facts necessary for important decisions.
 - 1.2 Usually many facilities and resources are necessary to complete the program.
 - 1.21 These must be brought together and organized according to a planned procedure under competent leadership.
 - 1.3 The time factor is important.
 - 1.31 The program should show results as quickly as possible. Investment in drawings, tools, machines, materials, buildings, and salaries pile up and emphasize the need for accurate planning to develop the program so it will have a good chance to earn an adequate profit.
2. The planning after a product is developed and ready for the market.
 - 2.1 The probable sales of each product for future periods must be planned in some manner so that the proper lead times will be available for procurement and fabrication.
 - 2.11 These sales forecast plans must be flexible to take care of changes in conditions.
 - 2.2 Methods, tools, equipment, machines, and space must be planned to produce at least the predicted sales quantities at lowest cost.
 - 2.21 These plans for actual manufacturing are usually crystallized and presented on operation sheets or other comparable forms.
 - 2.3 The kind and quantities of raw and purchased finished materials must be carefully planned, sometimes months in advance of their actual use.
 - 2.31 Enough of these materials must be on hand at all times, without excessive inventories, for the entire manufacturing program.
3. The amount of day-to-day planning varies with the product and the method selected for its manufacture.
 - 3.1 Continuous- and mass-produced products need a minimum of day-to-day planning for the flow of work through the plant.
 - 3.11 Extensive planning of plant facilities is necessary when the product is changed or if productive processes are up for revision.

- 3.12 Of course it is necessary to plan continually and correctly to have all the raw and purchased finished materials always available without excessive inventories.
- 3.2 Job shops and shops producing in regular and irregular manufacturing lot sizes must use the same machines in their shops to produce many parts.
 - 3.21 This involves careful advance planning to be sure each part or unit of product can be scheduled for the use of sufficient machine capacity to manufacture it when it will be needed.
- 4. Details of planning for production.
 - 4.1 Materials.
 - 4.11 Information, procurement, inspection, storing, and issuing.
 - 4.2 Machines, equipment, material handling, and methods.
 - 4.21 Routing-time relationships and operation sheets.
 - 4.3 Scheduling of due dates.

PLANNING FOR NEW PRODUCTS

When new products are contemplated or are actually in the stage of development, it is generally good practice to plan the progressive steps as far as possible. Chapter V discusses the usual sequence of events preceding the release of a new product. However, it is not always possible to predict the results of a complicated research or development program because unforeseen complications arise. In some cases progress can be accelerated by longer working hours or more men. If the various steps shown in Figure 1 are planned to be completed by certain dates, the supervisors in charge of the development program often can follow the plan by carefully checking at each stage to determine if they are on schedule.

Planning Outline for a New Development. Figure 1 illustrates in outline form how a development program can be planned for a fairly complicated new product. No new fundamental research was necessary but some rather serious design problems had to be solved before the machine was able to function properly. Note how the outline fixes dates at certain points.

Figure 2 was necessary almost from the start of this development because of the extra long lead time for some of the items. The purchasing department was asked for the current lead time for each group of materials needed for the finished product. The group with the longest lead time was decided upon first so that the material order could be placed in time to prevent delay in the delivery of the finished units.

OVER-ALL PROGRAM FOR DESIGN AND PRODUCTION FOR PRODUCT NUMBER 893 ex

DESIGN

1. Develop the first prototype.
 - 1.1 Largely done (August 1).
2. Develop second prototype to incorporate all the latest ideas which will not contribute an undue proportion of the prime cost of \$360.00.
 - 2.1 This is still largely in the experimental and cost analysis stage.
 - 2.2 Layout and design drawings shall be made during this period.

INDUSTRIAL ENGINEERING

1. No action necessary.
2. Production analyst works with design and experimental crews as a friendly critic asking for design changes which will make it possible to produce each part at the lowest over-all cost without impairing its function.
 - 2.1 A prime cost analysis must be made for each part and subassembly. As the work progresses, this cost is accumulated with the assumed prime cost as a goal.
 - 2.2 Production analyst with his crew will develop a graphic assembly list as the experimental work progresses.
 - 2.21 A progress report, with copies to Messrs. Smith, Jones, White, Brown, and Nelson must be made each Monday for the previous week.
 - 2.22 More men must be added if the final approval of parts for the making of working drawings is not up to the weekly schedule.

This should be largely done by December 1.

- 2.3 The compilation of the instruction and service manual shall be concurrent with the development of the second prototype.

- 2.3 Production analyst continues to work with the design and experimental crews on all parts and assemblies still in the experimental stage after December 1.
 - 2.31 Design will be frozen for the first series on December 31, (see item 6).

This work to be completed by December 31.

- 2.4 Inventory control shall initiate a stock card for each part upon notification by industrial engineering of its release.

FIGURE 1

OVER-ALL PROGRAM FOR DESIGN AND PRODUCTION FOR PRODUCT NUMBER 893 ex

DESIGN

3. Working drawings shall be started before November 1 as soon as any parts or assemblies are considered satisfactory by Mr. Anderson.
 - 3.1 Assuming 500 fabricated parts and assemblies in the finished machine, the working drawings should be made at the average rate of 65 drawings per week.
 - 3.11 Progress reports, with copies to Messrs. Smith, Jones, Brown, White, and Nelson should be made each week.
 - 3.12 On Monday of the following week, if the schedule of working drawings is not maintained, add more men to bring it up to schedule.
 - 3.2 The working drawings are to be made under the over-all direction of Mr. Black and a drafting supervisor with a crew housed as near the drafting room as possible.
 - 3.3 Working drawings are to be completed and approved by Mr. Jones by January 6 (see item 7).
 - 3.31 As these drawings are approved a unit requisition will be issued with complete specifications to industrial engineering by design engineering.
 - 3.32 Engineering specifications shall keep a file record of all purchased parts including raw materials to show at least three optional vendors approved jointly by design engineering and purchasing. Parts from different vendors shall be completely interchangeable. Close collaboration shall be maintained between design engineering and purchasing.
4. Simultaneously with design and production analyst activities under items

INDUSTRIAL ENGINEERING

3. Operation sheet writing shall keep up with all parts as they are released.
 - 3.1 Progress reports with copies to Messrs. Smith, Jones, White, Brown, and Nelson shall be made on Monday of the following week.
 - 3.11 The accumulated number of operation sheets, the number for the week, and the number of working drawings ahead of the operation sheets shall be reported each week.
 - 3.2 The production analyst and operation sheet writing crews are to be under the over-all direction of Mr. White, and Mr. Wood as supervisor.
4. As the operation sheets are written with the cooperation of the produc-

FIGURE 1 (Continued)

OVER-ALL PROGRAM FOR DESIGN AND PRODUCTION FOR PRODUCT NUMBER 893 ex

DESIGN

2 and 3 above, the tool design crew under the over-all direction of Mr. Brown, and Mr. Griffin as foreman, will work on the design of *all tools* * for product number 893 ex.

4.1 Sufficient tool designers must be on hand to keep up with all the working drawings and their operation sheets.

4.2 All tool design is to be scheduled for completion by February 15.

Work designated in 3 and 4 to be completed by February 15.

5. Tools shall be made in our own shop as far as possible. Whenever tools are too large to be made in our shop or if the accumulated load at any time is more than our shop can finish on schedule, subcontracting will be used to get the tools made according to schedule.

5.1 All tool records and responsibility for tools being made on schedule are assigned to Mr. Brown.

All tools are scheduled to be completed and tested by May 1.

6. The tool room shall anticipate its needs for tool-making materials and requisition it in plenty of time from the purchasing department to avoid delay.

INDUSTRIAL ENGINEERING

tion analyst, shop superintendent, and tool design, the tools to be used are given a number and name on the operation sheet by tool design.

4.1 Industrial engineering, methods section, shall check tool design to include motion study principles in the design and thus reduce the cost.

5. As tools are completed and inspected, industrial engineering will move them into the tool crib and issue work orders for trial runs to test them thoroughly for production purposes.

6. Simultaneously with activities under items 2 and 3, industrial engineering shall release requisitions for all material for production to the purchasing department as soon as the material specifications are frozen under item 2.

6.1 Industrial engineering shall ascertain the purchasing lead time on materials or items which are difficult to obtain. Drawings and complete specifications for parts using these materials must be scheduled for release in time to secure adequate delivery.

6.2 Industrial engineering shall specify the quantity and date required for all raw or purchased finished

* Tools include patterns, templates, jigs, fixtures, gages, dies, and special reamers taps, drills, etc.

OVER-ALL PROGRAM FOR DESIGN AND PRODUCTION FOR PRODUCT NUMBER 893 ex

DESIGN

INDUSTRIAL ENGINEERING

7. A third or production prototype machine is to be made, assembled, and operated by the experimental crew using parts and assemblies made by the production tools, or by hand methods if possible, within the tolerances specified on the working drawings as approved in item 3.31. The above machine fabrication and assembly is to be observed and inspected by the production inspection section.
- 7.1 The third prototype machine shall be given a thorough shake-down test to discover any "bugs" which may be present.
- 7.2 The instruction and service manual shall be carefully checked with the performance of the third prototype.
- 6.3 Industrial engineering shall decide which parts cannot be made in our own shop and arrange with purchasing to have the parts subcontracted to qualified vendors.
- 6.4 Purchasing shall notify inventory control of all purchase orders placed.
7. Industrial engineering shall initiate work orders for all production parts as soon as drawings, operation sheets, tools, materials, and equipment are ready to produce the parts.
- 7.1 Weekly progress reports on parts and subassemblies delivered into stock shall be issued to Messrs. Smith and Nelson on Monday to show the status of completed parts.
8. Industrial engineering is to develop methods in cooperation with the machine production department head for subassemblies and final assemblies by line principles. Set aside manufacturing space and develop the necessary fixtures, benches, and assembly tools to do the job as cheaply as possible.

*J. H. Jones
H. L. Nelson
Wm. Brown*

FIGURE 1 (Continued)

Note on Figure 3 how the various stages of the development program overlap. Each succeeding step was scheduled as soon as sufficient information was furnished by the preceding step.

August 15

ESTIMATED LEAD TIME * FOR CRITICAL ITEMS FOR POSSIBLE USE ON PRODUCT NUMBER 893 ex

Emerson Motors	1 yr or more	Transformer	6 mo
Motors (GE, Master, Packard)	10-11 mo	Graham Units	6 mo
Bearings (ball, roller)	9 mo	Gilmer Belts	5-6 mo
Bodine Motors	9 mo	Cabinets (after final approval)	5-6 mo
Stainless Steel Sleeves	7 mo	Perforated Tanks	5 mo
Alzak	6-9 mo	Weston Thermometer	4 mo
Stainless Steel Chain	9-12 mo	Rheostats	4-5 mo
Chain and Sprockets	6-9 mo	Micro Switches	4-5 mo
Gear Reducers	6-9 mo	Heater Rods	4-5 mo
Lead Sheath Cable	6-9 mo	Glass Tubes (Corning type)	4-5 mo
Wire	6-9 mo	Castings (aluminum)	4-5 mo
Most electrical equipment such as switches, timers, etc.	6 mo	Drive Rollers	3-4 mo
Voltmeters	6 mo	Hinges	3 mo
Blower Units	6 mo	Connectors	3-4 mo
Phenolic Products	6 mo	Defroster Hose	3 mo
Feedboards, Baseboards	6 mo	Nameplates (from time of in-quiring)	3 mo
Capacitors	6-9 mo	Special Washers	2 mo
Castings (grey iron)	6-8 mo	Sleeves (Gates)	2 mo

The above are only estimates, based on past performance. With special effort applied against each one the delivery time no doubt will be cut down. Special equipment made per our specifications will take the most time.

per N. Churvisky

* See item 6.1 under Industrial Engineering in Figure 1.

FIGURE 2. Lead time for critical items.

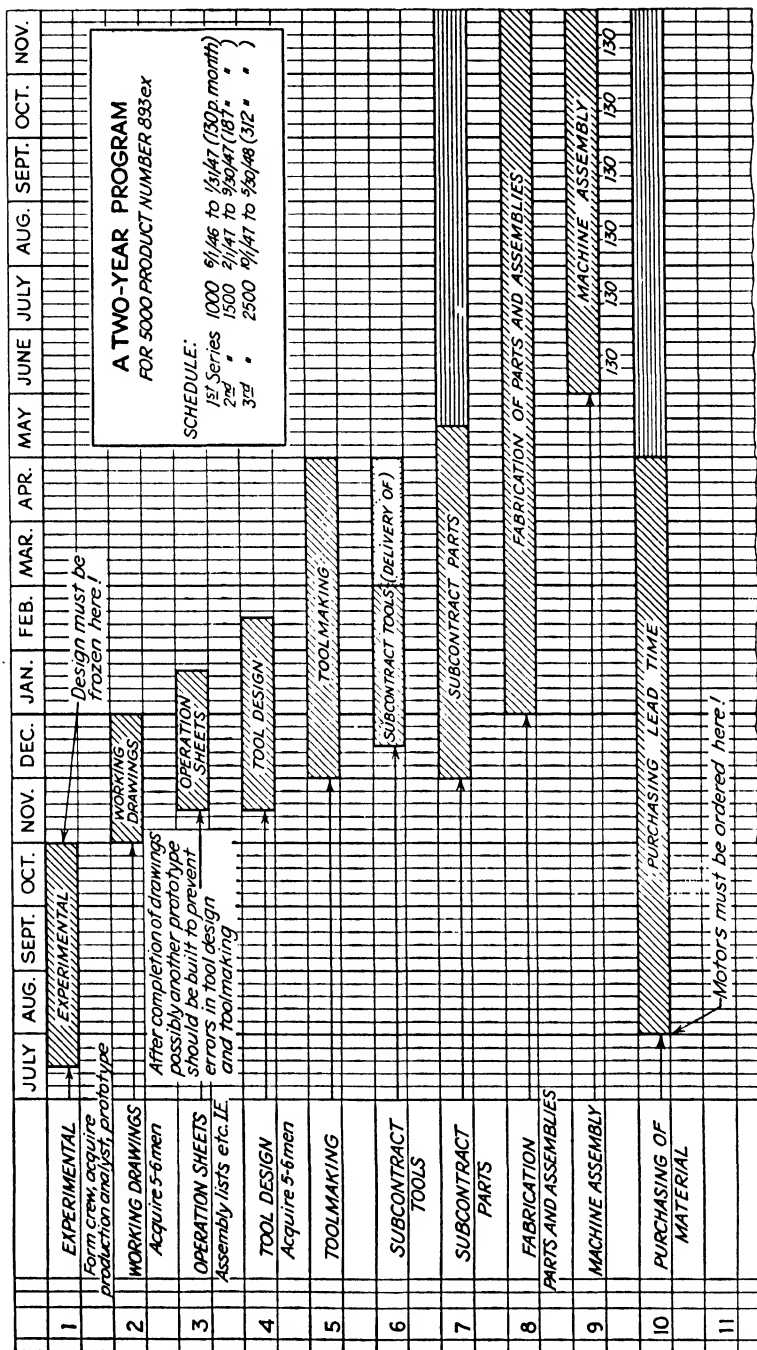


Figure 3. Graphic method to supplement outlined material of Figure 1.

Detail Plan of Steps in Developing a New Product. Each stage of the development program should have its own planned program to insure completion in time to fit the over-all plan. Figure 4 illustrates how successive steps in the design room were scheduled and how the industrial engineering operation sheets and inventory cards were coordinated with the release of the drawings of the new CA4 pump. The bold-faced figures were red on the original chart. These figures show where the performance was behind the planned schedules. As the red figures grew larger each day the supervisors would add more people to get out additional work to bring the actual cumulative totals up to the scheduled cumulative.

Usually a number of persons are involved in such a comprehensive program. Each group or division consisting of a supervisor with his men can be controlled by such plans so that each one will know what is expected far enough in advance to make the proper adjustments to get the work done. When any supervisor works with a schedule as shown in Figure 4, he knows from the first day whether he is performing according to the master plan.

Importance of Making Prompt Executive Decisions. As the routine portions of a plan for developing a new product proceed, it often is necessary to ask for decisions concerning certain difficulties or alternatives which cannot be answered by the routine personnel. If the facts are presented to a competent person or group along with the request for a decision, the proper answer should be forthcoming quickly. If not, the time to reach conclusions on controversial matters sometimes may hold up developments for days. Those waiting for a decision should stress that the entire development schedule will be delayed until their questions are answered.

Study the Need for New Resources and Facilities for Any New Product. Any important new development usually involves the additional use of present facilities or of facilities and resources to be acquired. When the development of a new product has progressed far enough to require a production program, it is necessary to plan the various steps to get it into operation as shown in Figures 1 and 2.

Importance of Time Factor. The time factor from the start of serious development to delivery of the first finished unit is quite important. Not only is the investment in drawings, tools, machines, materials, buildings, salaries, and wages increasing rapidly each day during the development, but often it is necessary to introduce a new product ahead of competing firms. The manufacturing advantage of being the first producer of a new product is sometimes greater protection against competition than a good patent would be. The usual large

Project-CA4 Pump Total estimated pieces-350		FEBRUARY																												MARCH							
		6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	1	2	3	4	5	6	7	8					
CA3	PARTS TO LIST																																				
	DAILY	50	50	50	50	50	50	50	50																												
	ACTUAL	50	50	68	67	65	50																														
	SCHEDULED	50	100	168	235	300	350	360	370	383																											
	CUMULATIVE	50	100	150	200	250	300	350																													
CA3	LIGHT NOS. - GAIN																																				
	BOLD NOS. - LOSS																																				
	CARDS TO RELEASE DAILY	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	10						
	ACTUAL	5	15	16	11	19	17	21	19	16	24	22	21	21	22	19	23	19	23	19	23	19	23	19	23	19	23	19	23	19	23	19	23				
	SCHEDULED	5	20	36	47	66	83	104	123	139	163	185	206	227	249	268	291	309	329	353	373	393	413	433	453	473	493	513	533	553	573	593					
CA3	NUMBER RECORD																																				
	ACTUAL	17	35	52	70	87	105	122	140	157	175	192	210	227	245	262	280	297	315	332	350																
	SCHEDULED																																				
	CUMULATIVE																																				
	LIGHT NOS. - GAIN																																				
CA3	BOLD NOS. - LOSS																																				
	DRAWINGS TO RELEASE DAILY	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17					
	ACTUAL	8	6	10	3	24	9	13	0	7	9	11	44	80	20	10	18	40	40	33	11																
	SCHEDULED	8	14	24	27	51	60	73	73	60	73	73	80	89	106	150	210	230	240	258	280	308	317	362	383												
	CUMULATIVE	17	35	52	70	87	105	122	140	157	175	192	210	227	245	262	280	297	315	332	350																
CA3	OPERATION SHEETS																																				
	DAILY	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17					
	ACTUAL																																				
	SCHEDULED																																				
	CUMULATIVE																																				
CA3	INVENTORY CARDS																																				
	DAILY	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17					
	ACTUAL																																				
	SCHEDULED																																				
	CUMULATIVE																																				
CA3	INVENTORY CARDS																																				
	DAILY	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17					
	ACTUAL																																				
	SCHEDULED																																				
	CUMULATIVE																																				
CA3	INVENTORY CARDS																																				
	DAILY	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17					
	ACTUAL																																				
	SCHEDULED																																				
	CUMULATIVE																																				
CA3	INVENTORY CARDS																																				
	DAILY	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17					
	ACTUAL																																				
	SCHEDULED																																				
	CUMULATIVE																																				
CA3	INVENTORY CARDS																																				
	DAILY	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17	18	17							

FIGURE 4. Detailed scheduling of design and industrial engineering work to coordinate with the over-all plan such as shown in Figure 1.

investment in a new product should be protected by profits from the sale of a volume output as soon as possible.

PLANNING FOR PRODUCTS TO BE MANUFACTURED

Effect of Product on Planning. The nature of the product and its method of manufacturing affects the planning procedure. Such products as flour, cement, steel, sugar, rayon yarn, bread, and some chemicals are made by reasonably stable processes in their plants. Each process was carefully selected at the time the plant was built and the machinery layout was designed to give the best possible flow of materials. The process is fixed until some innovation comes along to upset the old process. However, the maximum amount of careful consideration was given to the original planning when the plant's production facilities were in the layout stage.

The mass-production industries, such as automobiles, refrigerators, washing machines, and other products of high demand are similar in some respects to the process industries. While some of the products in this class may consist of hundreds or even thousands of parts, these parts are so planned when the plant is designed that they tend to flow along on conveyers to the point of sub- or final assembly in the correct quantities and sequence. The methods for any given time are almost rigid, and deviations from standards, at the request of the customer, are seldom allowed because of the large expense involved in such changes. The planning functions for the mass-production industries are partly done when the plant is prepared for the product. Planning for the materials to arrive when needed and for a high inventory turnover is a major function of the planning group in a mass-production industry.

Some plants cater to custom work or goods made to the customer's order. Complete planning for all engineering, methods, materials, men, and sequence of operations usually must be done to avoid confusion in the shop. If any engineering design work is necessary for the customer's order it should be included in the over-all plan to get the job out on time. The method of doing the work is planned in advance and routing instructions are prepared for the shop to follow. The materials, if not on hand, must be purchased and scheduled to arrive before the manufacturing program is due to start. If the order is one which increases the load in the shop, the planner should state how many men should be brought in to get the job out on time. In other words a special job is completely planned from the time the

order is received until it is shipped to the customer. To be sure, such hurried planning is not so exact as that done for the process or mass-production industries. Time usually does not permit the desired degree of accuracy, but advanced planning before the product reaches the shop keeps the shop employees on the job and the machines operating more consistently. It is by controlling such situations that profits are made.

Basis for Planning Activity. Production planning is the general term for a proposed method of action or procedure. It involves coming to a decision after examining the known data and estimating the possible effects of any intangible and incomplete portions of the sales information furnished. Chapter XVII discussed the coordination of sales and manufacturing; if the sales department takes the lead in preparing a sales forecast, it can provide an excellent basis for the start of sound planning for manufacture. The sales forecast is not a rigid promise to sell what was forecast six to twelve months ahead. Both manufacturing and sales must be flexible enough to revise the program up or down providing a reasonable time is set for changes to be absorbed. For instance, some manufacturing divisions need from three to six weeks to make the necessary adjustments to increase a manufacturing program. Usually it takes less time to reduce the production schedule in an orderly fashion. However, when production is curtailed, the incoming material commitments may be difficult to slow down quickly enough to prevent an excessive inventory if the material is not being used as fast as originally planned. In general a planned program can be changed in an orderly fashion providing that the lead time for procuring materials and manufacturing them is used as a basis for timing the change.

The sales department of the Minneapolis-Honeywell Regulator Company, a prominent manufacturer of many temperature, humidity, and aircraft control devices, submits to production control an estimate of the number of each device they expect to sell during the next period of three to six months. In the example shown, the memo from the sales department stated that 250,000 T11 units could be sold in the next four months.

However	3,000 excess units are in the local warehouse.
Therefore	247,000 units can satisfy the sales forecast.
But	25,000 units are needed to build up stock in other warehouses.
Thus	272,000 units are scheduled by production control for the next four months.

Or 16,000 units are scheduled per week as shown in Figure 5 which is one of four sheets in this tentative schedule. The other units shown in Figure 5 are scheduled in the same manner.

The materials for the scheduled production must be purchased with sufficient lead time to allow orderly purchases without expensive expediting procedures. The purchasing department furnishes a periodic résumé of the purchasing lead times for all the important materials. Figure 6 shows the number of months of lead time required for orderly purchasing of the materials listed on page 2. This important information is approved each time by one of the top executive officers. He is quite careful to check for any excess lead time, because if the vendor can and does deliver in less than the indicated lead time the investment in inventories may become excessive in a short time. Note how the lead time for any given material varies from one period to another.

While the sales forecast is an excellent method of building a manufacturing program, some manufacturers use other methods. Some plants have standing orders to be repeated at stated intervals. Unless the sequence is broken, such orders can easily be duplicated simply by repeating the planned procedure which was used for past orders. However, unless the product is entirely stable, changes in design or quantity will require some attention in detail before the new order can be released to the shop.

Some manufacturers have a line of products which may be entirely different from each other or they may be different but still have some common parts. When the orders come in irregularly and not in sufficient volume to warrant continuous production, such orders may be accumulated and the various similar or dissimilar parts or material requirements can be accumulated for stated periods or until a sufficient quantity to warrant an economic lot is to be ordered. (See Chapter XIX, pages 423 and 424.)

Sales and production programs are sometimes compelled to change owing to unforeseen events. In the dye industry, new colors released by competition may become fashionable and other companies must produce it or lose a large proportion of the season's business. Aggressive competition often brings out new products which are more or less secret until they hit the market places. If the product is unique enough and does an old job better or cheaper, the older product may need adjustments quickly to avoid trouble. Sometimes the buying public gets organized requests to stop buying products for some reason. For example, the *Reader's Digest* prints articles occasionally that

	3/3	3/10	3/17	3/24	3/31	4/7	4/14	4/21	4/28	5/5	5/12	5/19	5/26	6/2	6/9	6/16	6/23	Total
Therm																		
T491	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	8,500
T11	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	272,000
T21	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375	5,750
T81	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	170,000
T19	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0
T109	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	17,000
T801	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	36,500
T44	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	30,250
T45	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	8,500
T802	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	5,100
T442	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	45,500
T420	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	6,800
T42	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800	13,000
T92	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	4,600
T92L	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	4,050
Totals	35,350	35,600	35,600	35,725	36,225	36,325	36,325	36,325	36,325	37,575	37,825	37,725	37,975	37,975	37,975	37,975	37,975	628,550
Relay																		
R116	7,500	4,400	4,600	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,800	4,800	4,800	4,800	82,700
R117	5,700	9,200	9,400	9,800	10,000	10,500	10,500	11,000	11,000	11,300	11,300	11,300	11,300	11,300	11,300	11,300	11,300	177,500
R183	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	12,250
R182	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	4,900
R182	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175	2,975
R19	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	20,500
R132	425	425	425	425	425	425	425	425	425	425	425	425	425	425	425	425	425	16,150
R177	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	6,900
R100AC	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	2,000
R100DC	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	5,000
R114	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	5,000
R154	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	8,350
R161A	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	3,250
R161B	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	1,700
C516	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	1,700
R138	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	1,700
S400	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	500
S410	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	1,650
S610	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	7,000
Q174	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	3,480
R482A	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	250
R482C	185	185	185	185	185	185	185	185	185	185	185	185	185	185	185	185	185	300
Totals	17,775	18,275	19,325	19,925	20,625	21,075	21,225	21,425	21,425	21,925	21,925	22,525	22,525	23,025	23,025	23,025	23,025	362,475

FIGURE 5. Schedule used for planning production program. Revised tentative MH production schedule.

Page 2

No. of Months as of:

	GAD	GAD	GAD	GAD
	May 1	June 17/47	8/12	10/24
MATERIAL				
Thermometal	4	2	2	2
Nickel Invar	3	3	2	2
"Z" Nickel	3	3	2	2
Nickel Silver	3	3	2	2
Nichrome	3	3	2	2
Resistal	6	4	4	4
Screen, brass	2	2	2	2
Tauril Packing	2	2	2	2
Velbestos	2	2	2	2
Vulcoid	4	2	2	2
Rogers Board	2	2	2	2
ROD				
Aluminum Rod	1	1	1	1
Bakelite Rod	2	2	2	2
Bessemer Rod	4	4	3	3
Brass Rod ($\frac{3}{8}$ " & under)	2	1	1	1
Brass Rod (over $\frac{3}{8}$ ")	1	1	1	1
Bronze Rod	4	3	2	2
Copper Rod	4	3	2	2
Drill Rod	2	2	2	2
Duronze Rod	3	3	2	2
Allegheny Metal Rod	3	3	2	2
Invar Rod	3	3	2	2
Monel Rod	1	1	1	1
Music Wire	1	1	1	1
Pinion Rod	3	3	2	2
Armco Iron Rod	1	1	1	1
Steel Rod ($\frac{3}{8}$ " & under)	4	2	2	4

FIGURE 6. List of purchasing lead times, approved each time by GAD.

present certain facts about prices and trade practices. One article was concerned with the wide spread in prices for different brands of the common drug, aspirin. The companies with the higher prices are trying to combat the article by increased advertising to show that their product is worth more. Such articles can change buying habits, and the affected plants must make adjustments in their production. In any event, the sales and production program can be upset considerably by such public whims.

In some industries, backward seasons cause real sales slumps, and unless production is closely geared to inventories in such industries the result can be disastrous in bad years.

In general, it is better to plan for production on the conservative side. If sales fall below the estimated production, the loss is less. If sales are greater than the planned production, it is usually possible to increase production by overtime or by subtracting or adding space and equipment if sufficient material is available.

Planning for Methods. Chapter IX discusses the problem of selecting the economical method for doing an operation. In repetitive work the method is all-important, since small savings accrue to sizable sums when the quantity is large. However, for special work the selected method is based more often on the available tools and equipment in the shop rather than on any special tools or machinery. Equipment, tools, and "know-how" are potent factors in choosing the methods to be used for short-run jobs. Occasionally, certain parts can be made cheaper and often faster if they are subcontracted to a shop which has specialized equipment. If the part is to have a long run, a decision must be made whether it is wise to acquire the specialized equipment or continue to subcontract (see Chapter XV). This sort of planning should be done before the actual detailed planning for the product is released to the selected shop.

When repeated orders, standard products, or long runs on special orders are encountered, it is wise to plan carefully all methods in detail and to select the one which will produce at the lowest unit cost. The crystallized plan should be described on an operation sheet (see Chapter XI) which becomes the official method for doing the job. It is not necessary to think about the operation sheet for each rerun of a job unless the product changes or a new production technique is developed.

It may be necessary to specify the class of labor which should be used for an operation. This is not so important as it used to be, since labor rates seem to be moving towards a common rate for many classes of machine work. However, if there is a differential in wage rates

between classes of work and machines, the planner should specify the labor class to be used on each operation. The type of inspection also should be specified on the operation or route sheet so that the product is adequately inspected at lowest cost.

Planning for Productive Materials. The kind and quantities of raw and purchased finished materials must be carefully specified and planned. The purchasing lead time determines to a large extent when the order must be placed. The quantity to be purchased and stored should be determined by the requirements and the economic purchase quantity (see Chapter VII). The determination of the material requirements for a production program is a detailed operation which may be accomplished in a number of ways. Where the products are simple and the production requirements are not too heavy, the inventory control procedure described in Figure 6, Chapter XIX, can control the ordering of raw and purchased finished materials very well. However, if many parts or products use the same materials, the procedure may become quite involved for procuring and controlling adequate supplies of that material.

The planning for some widely used materials may be changed from the actual requirements necessary for all the various uses to an order point-reserve stock-economic lot size calculation as discussed in Chapter VII. Examples of such materials could be $\frac{1}{4}$ " by 1" by 20 cap screws, $\frac{1}{2}$ " by 12 hex nuts, or $\frac{3}{8}$ " lock washers for metal-working plants and common salt or sulfuric acid which are so commonly used in many chemical and process plants.

Production and Material Planning for Process Industries. Figures 7 and 8 are examples of a method for planning the production for dye XYZ, code number 61267. Dye XYZ is made from five other dyes—ABC, FGT, CQ, HT, and JH—as shown in section 10 of Figure 7.

The sales forecast for dye XYZ is projected at least six months in advance of the current month. Without going into the technical details of how this forecast is obtained, Figure 7 shows how it is presented to the production control department. The form is duplicated on both sides so that one sheet is good for twenty-four months. This forecast must necessarily be quite flexible. Style considerations and other factors make the dye industry subject to many variables. For this reason the form in Figure 7 contains several spaces where changes in the projected program may be entered as they occur. In addition, the "actual" columns are reserved for the final adjustment which must be known at least one week before the first of the current month.

The January, February, and March actual requirements are the same as predicted (six months previous), but the April actual require-

Economic Production Program 3000 Lb
 Mfg. of Economic Program Req. 10 Days
 Batch Size 5000 Lb Min. Program 5000 Lb

Code Number 61267
 Product Name XYZ

PRODUCTION SCHEDULE
AND
INVENTORY CONTROL

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1 Estimated requirements for current month	1000	1000	1200	1500	2500	1500	2000	1200	800	800	800	1000
2 Inventory on first of month												
2 In process	2000	2000	1000	1000	1000	1200	500	500	This row from sales forecast kept 6 months ahead.			
2 Finished	5000	4625	5000	4625	5000	4625	3800	3425				
2 Total	7000	6625	6000	5625	5000	4625	3800	3425	2300	925	1100	1425
3 Est. prod. - No. 9 previous mo.	0	0	0	0	0	0	0	0	0	0	0	0
4 Total of No. 2 and No. 3	7000	6625	6000	5625	5000	4625	3800	3425	2300	925	1100	1425
5 Subtract requirements for mo.	1000	1000	1000	1200	1500	2500	1500	2000	1200	800	800	1000
6 Calc. inventory, end of mo.	6000	5625	5000	4625	3800	3425	2300	925	1100	1425	1700	1425
7 Est. use for next 2 mo.	2200	2200	2700	3000	3000	4500	2700	2100	2500	1700	1800	1600
7 If No. 7 is greater than No. 6, difference is prod. in No. 8	Est.	Est.	Est.	Est.	Est.	Est.	Est.	Est.	Est.	Est.	Est.	Est.
8 Calc. prod. for next mo.	0	0	0	0	0	0	700	3575	0	0	1575	600
9 Sched. prod. for next mo.	0	0	0	0	0	0	3000	5000	0	0	3000	1500

THE ABOVE PRODUCT CONSISTS OF THE FOLLOWING DIRECT CONSTITUENTS.

	750	1250	750	375	375
Code No. 9078 % 25					
Name ABC					
Code No. 8095 % 55	1650	2150	1650	825	825
Name FG7					
Code No. 7609 % 10	300	500	300	150	150
Name CQ					
Code No. 8323 % 6	180	300	180	90	90
Name HT					
Code No. 6214 % 4	120	200	120	60	60
Name JH					
Code No. %					
Name %					
Code No. %					
Name %					

THESE COLUMNS ARE CALCULATED AS FOLLOWS:

Code No. 9078 % 25	Direct constituents are calculated from theoretical requirements for the product XYZ.
Code No. 8095 % 55	The percentage figure shows how many pounds of materials ABC, etc., are required for 100 lb of material XYZ.
Code No. 7609 % 10	See accumulation sheet for total requirements of material ABC as used in all products requiring material ABC.
Code No. 8323 % 6	
Code No. 6214 % 4	
Code No. %	
Code No. %	
Code No. %	
Code No. %	

Year 1948

Group Acid Blues Class AB

Product Name XYZ

Sheet No. 1 of 1 Sheets

FIGURE 7. A method for controlling production in a process industry.

ments were increased by 1,000 pounds on March 17. Since this was known in March, it was possible to adjust the April actual requirements on April 6 to include the extra 1,000 pounds needed for April. This particular adjustment did not exhaust the supply which was available for April. However, it did make it necessary to schedule 5,000 pounds of XYZ during May to build up the inventory for the next two months. Note that the increased estimated use for the next two months in the April actual calculation column also increased the requirements for the direct constituents as shown for April. Since these increases were known or on before April 6, the increased amounts could be made in April to care for the increased requirements in May and June.

Many dyes are made by mixing two or more other dyes to get the proper shade and other properties. Dye ABC is made by mixing five direct constituents. An accumulation sheet, Figure 8, is prepared for each of the direct constituents to show all their uses for mixing. In addition the requirements for direct sales of each dye and intermediate is obtained from the sales department. The combined use for mixing purposes and for direct sales are entered as item 1 in Figure 7. Direct sales are estimated six to twelve months in advance and any final change in these estimates must be sent to production control by the sixth of the month in which the product is to be manufactured.

Thus Figure 7 is used to plan the production and to control the inventory of one dye or intermediate. In turn this form lists the amount of the important ingredients required each month. Figure 8 then accumulates all the various mixing requirements from other sheets similar to Figure 7 to get the total requirements for each constituent, say ABC. Then the direct monthly sales, both estimated and actual, for product ABC are added to the accumulated requirements for mixing as shown on Figure 8 and the total becomes item 1 for each month on a new production schedule and inventory control sheet for ABC similar to Figure 7. The direct constituents for ABC are also calculated and accumulated until the production schedule and inventory requirements are known for each dye and intermediate manufactured in the plant. Most of the common chemicals such as sodium chloride, the common acids, and aniline oils are purchased and controlled by the order point-reserve stock-economic lot size method (see Chapter VII).

Figure 10 of Chapter V shows a graphic chart of ingredients for a rather simple synthetic dye. The various intermediates shown on this chart are accumulated on their own sheets similar to Figure 8

ACCUMULATION SHEET
Listing All the Products Which Use
and also how much is needed and when it is to be used

Sheet No. 1 of 1 Sheets ABC Cons No. 9078

Cons No.	PRODUCT NAME USED AS OR MATERIAL	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	YEAR
10001	DEF. XYZ				750			375						
	ACT. XYZ				1250		750	—	375					
11203	DEF. DEF			1200		890	895	700	655					
	ACT. DEF													
11309	DEF. HCB	300			550	340			785					
	ACT. HCB													
9446	DEF. BCH				122			346						
	ACT. BCH				195									
	DEF.													
	ACT.													

These figures are taken from section #10, Fig. #7,
and are entered under the same month in which they
are shown in Fig. #7.

DEF.														
ACT.														
DEF.														
ACT.														
DEF.														
ACT.														
SUBTOTAL ON TOTAL DEF. ACT.		300		1200	1422	1230	895	1421	1440					
		300		1200	1995	1230	1645	1046	1815					

This row shows total theoretical requirements for first intermediate ABC based on the sales forecast for the finished products XYZ, DEF, etc.

YEAR 1948 GROUP Acid Blues CLASS CQ PRODUCT NAME ABC Cons No. 9078

FIGURE 8. Accumulation sheet for intermediate ABC to show total usage. Bold-faced figures designate red for actual.

until the single ingredients are listed which are controlled by the order point-reserve stock-economic lot size method.

The forms shown in Figures 7 and 8 not only plan and schedule the production to provide finished products for the sales requirements but also act as a method of inventory control for all intermediates and finished products. Since the control is based on the requirement of the next two months following the month of calculation, the average inventory of all products should be about one month's supply unless the economic lot size is larger than this. This one month's average is based on the fact that the scheduled production for the next month for all intermediate products usually averages one-half month ahead of their use which is during the following month. By the same reasoning the use or sale of any intermediate or finished product would be over the second following month with an average for all products of about another one-half month or a total inventory turnover of about once per month.

Material Planning for a Complicated Industry. The Minneapolis-Honeywell Regulator Company has a very complicated combination of materials which must be carefully controlled to avoid excess or inadequate inventories. After the sales forecast is rearranged by production control as discussed on page 386 and shown in Figure 5, it is necessary to accumulate the requirements for all possible uses of each material. This is done by the punch-card-tabulating method to get the quantities for each material quickly. The procedure is shown in outline form below.

1. Design engineers furnish a parts list showing the part number and name of each part used on each device. In addition the number required of each part is also listed on the parts list.
2. A deck of IBM cards is punched for each device to cover all the parts included in its parts list.
 - 2.1 A red stripe IBM card is punched for each part used in every device to include the part number, number of parts used, and the device. See Figure 9.
3. One blue stripe IBM card for every part which is used in the entire production program is punched to include the part number, total weight per 1,000 pieces, and the material code number. See Figure 10.
4. Each red stripe card (Figure 9) as punched in 2.1 is run through a multiplier with card #1 (see Figure 11).
 - 4.1 When the red stripe card which has the part number and the number of parts used per device is multiplied by the scheduled quantity for that device, a new card, #2 (Figure 12), is automatically

[illegible]

FIGURE 9. Tabulating card with red stripe, punched to show part number, number of pieces used, and device the part number is used on.

[illegible]

FIGURE 10. Tabulating card with blue stripe, punched to show part number, weight per 1,000 pieces, and the material code number.

[illegible]

Part Number	Total Usage
13198	390
13199	390
13204	3365
13205	3365
13207	6855
13208	6855
13209	6855
13213	3665
13217	3665
13220	6855
13224	6855
13228	2800
13229	6855
13230	6855
13231	2800
13241	2800
13252	24080
13253	390
13272	20350
13273	16985
13274	356685
13275	22195
13276	36240
13286	390
13287	390
13288	390
13291	16085
13292	390
13296	390
13370	2800
13379	1560
13380	390
13389	790
13392	390
13393	390
13395	390
13516	400
13517	790
13523	790
13575	745
13581	520
13582	520
13658	390

FIGURE 13. Sheet from tabulating machine which shows the quantity of each part number used for all the scheduled devices.

Material Specifications				3rd Quarter	
Material Example →	22	0098	14	2060	238
	22	0077	14	2770	59
	22	0179	14	2885	902
	22	0077	14	3235	245
	22	0077	14	3355	2322
	24	0060	14	2370	
	24	0060	14	2805	527
	26	0777	14	0032	48
	28	0040	14	0095	1620
	28	0040	14	0160	3122
	28	0040	14	0180	3987
	30	0120	14	2095	4
	30	0120	14	2170	37
	30	0019	14	2180	4595
	30	0159	14	2375	1637
	30	0016	14	2395	20
	30	0019	14	2395	3506
	30	0120	14	2515	4
	30	0020	14	2520	907
	30	0016	14	2525	4462
	30	0019	14	2525	1384
	30	0117	14	2650	36
	30	0016	14	2655	15412
	30	0019	14	2665	5196
	30	0020	14	2665	812
	30	0023	14	2695	9217
	30	0037	14	2800	126883
	30	0202	14	2840	1760
	30	0016	14	2915	1326
	30	0019	14	2915	9187
	30	0021	14	2955	799
	30	0021	14	2970	365
	30	0037	14	3065	659614
	30	0019	14	3125	95286
	30	0016	14	3145	85625
	30	0023	14	3190	91
	30	0171	14	3205	
	30	0019	14	3225	98818
	30	0016	14	3245	4735
	30	0019	14	3245	52345
30	0037	14	3270	239990	
30	0037	14	3300	5693	
30	0023	14	3330	1401	
30	0037	14	3390	636721	

FIGURE 16. Partial list of gross material requirements for 1947.

- 11.1 These special cards, see Figure 18, are marked by pencil on the right-hand side to show the quantity of material on hand as listed in the material control ledger. See Figure 8, Chapter XIX.

[illegible]

FIGURE 17. Monthly requirements for material #30-0037-14-3065 as shown for the third quarter in Figure 16.

12. Card #4 (Figure 15) is run with the mark sense card (Figure 18) in a tabulating machine to get the net amount of material to be purchased. Sometimes there is a surplus which is listed on the tabulating sheet as a credit when the material on hand is more than the requirements for the period.

[illegible]

FIGURE 18. Tabulating card marked with a pencil to list quantity of any material on hand.

- 12.1 If any surplus is large enough it is listed for management's attention.
- 12.2 The net quantity of material on the tabulating sheet for each material, which is left after the on hand inventory has been de-

plant; sometimes within the same plant different departments must use different planning methods.

The Minneapolis-Honeywell procedure for controlling the hundreds of different materials used to make the many devices produced necessarily is complicated and precise. Over \$3,000,000 worth of materials is purchased per year. Inventories must be checked often to detect excesses and shortages. Consequently, a highly developed system of control is essential to do more and more mechanically and to make the system more responsive to changing conditions. The system for production control in any given plant should be specially devised to do only what is necessary for the job at hand.

The same elements of control are present in the Minneapolis-Honeywell Regulator Company's complex planning problem as are present in the simpler ones. The main difference lies in the size of the problem, the emphasis, and the speed of accomplishment. Searching for the right data, hand posting, and calculation of such an array of parts, materials, devices, and schedules would require a large number of people.

One of the most important aspects of planning for production is to state the date when the various components should be completed in order to fit into the master schedule for completion of the entire unit or production schedule. This involves delivery dates for raw materials, subcontracted parts, and purchased finished parts. It also means that the various sub- and final assemblies along with their parts or components should have due dates set so that they will flow into the stock or accumulation area shortly before they are needed. If they arrive very much too soon the process inventory is unnecessarily large; if they arrive too late the work schedule is held up. Planning for delivery dates and still maintaining low process inventories is an exacting procedure which depends on accurate shop information and shop executives who are trained to respect the official shop schedules.

QUESTIONS AND PROBLEMS

1. What are the important differences in the operation of a factory with a planning department and without one?
2. What effect does the product have on planning procedures?
3. What effect does the quantity produced have on planning procedure?
4. What new functions does a planning department introduce?
5. Why are the rates of both production and total annual production important to a good program of control?

6. Follow dye XYZ through the first six months along with its first direct constituents to check the accuracy of the posting.

7. What facts must be available quickly to properly plan materials and production when the form shown in Figure 6, Chapter XIX, is used.

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CHAPTER XIX

INVENTORY CONTROL

In its broadest sense, *inventory is any list of property*. However, in an industrial sense, as treated here, the manufacturing inventory includes only those materials entering directly or indirectly into the product and those materials, sometimes known as supplies, which aid production but do not necessarily enter or stay with the product. (See pages 83 and 84.)

Practically all industrial executives know that inventories of production materials are important. However, when no planned procedure for controlling inventories is used, they may be seriously out of balance with actual production needs. For each plant there should be an optimum inventory which will be consistently ahead of production but within carefully controlled limits. Some plants do not know what their optimum inventory should be. Other plants are so badly organized, from a production control standpoint, that even if they know what their inventories should be they cannot take full advantage because no organization exists to do it.

This chapter will discuss the type of situation which may affect inventories and several standard procedures which can be used to control them for minimum costs.

Inventory control is a procedure by which the quantity of a material is theoretically held between predetermined limits. Modern inventory control has reduced the risks of depreciation and obsolescence of stored materials; it has removed much of the necessity of storing and transporting materials in and out of warehouses and storerooms; it has made large reductions in factory floor space by better control of the process inventory; and it has speeded up production by providing the correct amount of material when it is needed for production.

It is well to remember at all times that excessively large inventories may prevent the flexibility which is so necessary in many industries. An inflexible situation caused by excessive inventories may prevent or retard desirable engineering and method changes. If a major order is cancelled, any excessive material on hand may cause a serious loss if the material becomes obsolete as a result of the can-

cellation. In other words, inventories in themselves do not create income. They are an expense to maintain; they are subject to losses from depreciation, obsolescence, and possible theft; and they usually cannot create income until they are sold in the finished product.

Effect of Improved Transportation on Inventory Control. There are certain types of plants in the mass-production field such as automobiles and radios which have reduced their inventories from several months' to several days' supply and in a few instances to a matter of hours. This improvement has been made possible in part by the dependable transportation service built up by the railroads. The resulting improvement in the railroad's equipment and other operating factors has made it possible to increase the number of scheduled fast freight trains. Trains were made up at terminals to allow through runs without dropping or picking up cars along the route. New and better designed locomotives reduced the need for frequent running repair. Freight engines are now run from four to eight hundred miles without shop care, whereas one hundred and fifty to two hundred miles formerly was considered good. Distinct progress has been made in reducing time required at terminals for making up trains and delivering cars at destinations. Throughout the entire railroad system there is a new conception of the value of time.

The shipper of small lots of less-than-carload freight also finds similar improvements in the movement of his freight.

Because of this prompt and reliable service, the typical manufacturer now realizes real and substantial savings in being able to carry less inventory in his own plant. In the retail lumber industry alone it has been estimated that about \$600,000,000 less capital is needed because about four billion less board-feet of lumber need to be carried than before. It also has been said that the modern freight car to a considerable degree can serve as the raw material storeroom in today's industries.

The motor freight network which has developed in the United States has been a large factor in inventory control. Dependable overnight service in most industrial communities makes it possible to move ordinary materials at express speed from factory door to factory door. Thus within a radius of several hundred miles a purchasing agent may obtain shipments of raw or finished goods overnight. Such quick service from dependable vendors makes it unnecessary to carry excessive inventories as a protective measure against unpredictable and unreliable transportation service.

Effect of Type of Industry on Inventories. All manufacturing falls somewhere between two broad classifications: continuous or intermit-

tent. Generally all types of food canning, grain milling, cement manufacturing, mechanized bakeries, automobile plants, and sugar refineries are good examples of continuous manufacturing in which practically all machines are used during the time the plant is running. Manufacturers of large steam or water turbines, producers of special machinery and equipment, and other products made to order are good illustrations of intermittent operation. However, many factories have both continuous and intermittent manufacturing processes going on at the same time. The more complicated this intermingling of continuous and intermittent processes becomes, the more difficult will become the system for material control, and the greater the necessity for controlling it.

Inventory Turnover. *Inventory turnover is the number of times (usually in a year) the inventory is sold and replenished.* This figure will vary in different businesses, from the vegetable and fruit peddler who may replenish his stock once or twice during the day to the manufacturer of large telescopes where necessity decrees that several years must elapse to complete one instrument.

The proper method of computing¹ the turnover for a business as a whole is to divide the average annual inventory, based on the monthly statements, into the sales for the year. This figure is sound for making general comparisons from year to year, but in manufacturing industries it is important to get detailed turnover figures for the several departments or different products produced. Moreover, detailed figures for each class of inventory, such as raw materials, work in process, finished stocks, and sometimes supplies, will provide many useful facts. Turnover of raw materials should be based on the value of the average annual raw material inventory (based on monthly statements) divided into the value of raw materials which have entered process during the year. Turnover of work-in-process inventory is based on the value of the average annual work-in-process inventories divided into the value of products completed during the year as represented by credits to work-in-process accounts. Turnover of finished goods is based on the value of the average annual inventory of finished goods divided into the value of annual sales.

Various Inventory Carrying Charges. The cost of carrying inventory is affected by several charges, each of which is subject to some degree of control. Interest, taxes, and insurance on the average investment in the various kinds of inventory vary directly with the physical volume and the current rates of interest, taxes, and insurance. Some

¹ L. P. Alford and J. R. Bangs, *Production Handbook*, Ronald Press, 1945, p. 403.

companies like to see their investments in inventories, machines, and method changes return at least as much as their regular earnings on the company's capital investment. That is, any investment should return above the normal costs, such as common interest, taxes, and insurance, enough to equal the gross earnings of other capital in the business.

A change in methods of processing materials often has an important effect on inventory volume. Sometimes the change of methods involves a change in materials handling, which in turn affects the process inventory by reducing the storage time of materials between operations.

The charge for storage, which includes all the inherent costs for enclosing space and administering it, with the addition at times of extra charges for special services such as controlled temperatures and humidities, may vary directly with the volume of inventory. However, if vacated space lies idle, not all the apparent savings are forthcoming because some of the charges for storage go on whether the space is used or not.

There is less chance for depreciation, shrinkage, and obsolescence losses if the inventory can be reduced. The various charges usually should be considered separately so that the proper analysis and control can be used for each one. Such an analysis will show the way to increase inventory turnover.

METHODS OF REDUCING INVENTORY

There are a number of ways in common use which help to decrease inventory and thereby increase the rate of turnover. Probably the most important factors contributing to decreased inventories are the previously mentioned improved transportation systems in America, proper planning, layout, work simplification, and the concomitant materials handling system. During the last thirty years these five factors alone have reduced the capital requirements of industry by thousands of millions of dollars under what they would be now if old methods were still used. American railroads reduced their inventories over \$235,000,000 from 1920 to 1927.² Part of this decrease was due to lower prices, but the major savings were due to better inventory control. The railroads took advantage of their own improvements in rail-service dependability to carry smaller stores of repair parts and supplies in their various supply depots.

² *Recent Economic Changes in the United States*, McGraw-Hill Book Co., 1929, Chapter 4, p. 291.

Effect of Standardization on Inventories. Standardization in its many forms, such as simplified practice for certain industries, standard specifications, and standard tools, has been a method of reducing inventories second only to better transportation, planning, layout, and materials handling. There are many examples of actual results that can be quoted: ³

Eighty per cent of our business came from 2,000 varieties of this product. This was 3.6% of our full line. The other 96.4%, amounting to 53,000 varieties, brought in only 20% of the business. Adherence to the Simplified Practice Recommendations has brought about, among other advantages, a saving in inventory of \$225,223 and a saving of \$13,500 a year in reduced obsolescence costs.

Standardization of small tools reduces the variety which must be carried. The Chrysler Motor Car Company reduced the number of different types and sizes of grinding wheels carried in their stockroom by over 50 per cent by standardizing spindles and guards on their grinding machines.

Standardization of parts or units of a product often leads to cost reductions which are reflected in the inventory of these items. This occurs because standardization usually results in carrying fewer varieties of parts and standard parts generally cost less per unit. Fairbanks Morse Company used to pay \$50 to \$70 per hundred for special screws for a certain job. Now they pay \$9 per hundred for standard screws to do the same job. The Minneapolis-Moline Power Implement Company used to pay 25 cents for hose clamps. When a standard automobile-type hose clamp was adopted, the price was lowered to 12 cents.

Effect of Purchasing Policy on Inventory. The size of raw material inventories depends to a great extent on the purchasing policy. Hand-to-mouth buying will reduce raw material inventory to zero if it is carried far enough, but the unit cost of the product may be higher with this plan. An analysis of the proper economic quantity to buy should be made by some method (see Chapter VII) that will strike the proper balance between the cost of maintaining a raw material inventory and the final product cost. If material is purchased for a special job order, the entire requirement for the job is usually requisitioned by production control.

Effect of Seasonal Peaks on Inventory. Finished product inventory is dependent on the relationship between sales during any given period and production. Fortunate indeed is the business that can produce

³ L. P. Alford, *Cost and Production Handbook*, Ronald Press, 1934, p. 319.

and sell practically the same amount at all seasons. Most business firms have peaks and valleys in their sales and often the finished inventory stock is allowed to take most of this shock. (See Chapter XVII.) Since seasonal peaks are often the result of a combination of buying habits and climatic variations more or less beyond control, it is seldom economically feasible to have manufacturing schedules follow the short-term sales demand. Because of the increased capital invested in equipment, if production is to follow sales, the machinery would be idle and the factory personnel would need to be expanded and contracted periodically. Finished goods inventory sufficient to carry over the sales peaks will allow the plant to run more nearly at a constant capacity with a minimum of capital cost for the plant.

Necessary Large Inventory Variations. Certain types of industry, where all or a large section of the operations must be done within certain limited seasons, have violent employment peaks and valleys. The cutting of trees for the lumber industry during the winter months, the quarrying of stone during the summer in northern sections, the canning or packing of food products when the products are ready, sugar campaigns—all require intensive action for short periods of the year. These products are held either for further operations or in warehouses from which they are sold fairly evenly throughout the year. Finished goods inventories of this type necessarily reach the highest point at the end of the production process.

Effect of Methods on Process Inventory. The amount of process inventory is governed to some extent by the length of the productive process. Although production control has succeeded in reducing the process time in many industries, in some plants the process is assumed to be fixed. This has been proved so often to be wrong after concentrated research and study that industrial engineers are skeptical of all processes. The automobile plants were among the first to visualize the possibilities of reducing the time their product remained in the plant.

Because of the thousands of separate parts needed in a modern motor car, the plant layout was designed to make these parts move over the shortest possible paths toward the assembly lines. Since process inventory and the cost of maintaining it involve material lying in inactive banks at each production center as well as the material actually in the machines, the layout was designed to reduce to a minimum the necessity of material banks.

Fundamental changes in the methods of producing goods cause the inventory to go up or down, depending on the change involved. A shift from castings to drop forgings usually means an increase in

raw material inventory (see Chapter VI). When die castings were substituted for sand castings in the manufacture of carburetors the processing time was tremendously reduced with a corresponding reduction in the process inventory. The constant improvement in methods brought about by a good motion study program tends to reduce the process inventory as well as the labor cost.

In a test case a complete automobile has been built in five and one-half days from digging the iron ore to delivery of the finished car. Not so long ago the painting of the body alone took from twenty-one to thirty days, depending on the price of the car. About three-fourths of this time was necessary to dry the many coats of lead and oil paint. High-speed lacquers and paints have reduced this to a matter of hours and the new finish is far superior to the old lead pigment, oil, and varnish method.

The greatest economy of time in processing materials is obtained when movement from one operation to another is reduced to a minimum. For the mass-production plants with their various conveyers and line production this concept has been well developed. For every high-production plant of this type, however, there are many that cannot use line production, and conveyers would be of little value. Yet analysis of the over-all production time in most factories would show that a larger part of this time is consumed in handling the materials between operations than is consumed in the actual operations themselves. For this type of plant, the simple rearrangement of departments and their equipment often would reduce over-all production time and thus greatly decrease the investment in process inventory.

Floor Space Reduced When Inventory Drops. Every time the raw and finished materials inventory is reduced by any means, the demand for storage space is also reduced. The various charges against floor space, such as heat, light, interest, depreciation, maintenance, and administration, are practically constant for storage space. For this reason, space released by the reduction of an inventory must be used for other purposes to effect a saving. If any relinquished space remains idle, no saving has been made unless a whole section is released so that a saving results in light, heat, and janitor service.

Some types of storage require special services such as refrigeration, special temperatures, humidity, and ventilation. These services increase inventory costs and often such storage space is purposely divided into smaller rooms to provide flexibility for the varying storage demands.

Some Storage Losses. When inventories of certain products are reduced, the possible losses from depreciation, shrinkage, and ob-

solescence are less. These losses often are serious enough to be the driving force for the reduction of inventory. High turnover is essential for some food products such as yeast, roasted coffee, baked goods, fresh fruit, and vegetables. With many products inventory losses from depreciation are largely a function of time, although carelessness in handling or storage conditions also are important causes of depreciation.

Shrinkage occurs from evaporation, sublimation, theft, inaccurate measuring, or plain waste. Gasoline, ether, and other volatile liquids are difficult to hold in containers with poor stoppers. Dry ice slowly sublimates unless kept at very low temperatures.

Obsolescence is an unpredictable source of loss and may occur at any time to many products. It can be reduced by having the engineering or specification departments ascertain the amount of old stock on hand before a change in materials is made. In a young or fast-changing industry, obsolescence of material is often a source of serious losses where inventories get out of control.

Necessary Aging Affects Inventory. Certain types of factories manufacture products which require short process times along with only several days' inventory at any one time. Other manufacturers may have products which must be aged before they are ready for use. Sometimes this aging must take place before the production processes are finished and sometimes the goods are finished except for aging. In any event, either of these aging problems adds to the amount of material on hand, reduces the inventory turnover, and incidentally adds to the cost of doing business in that product.

A number of things such as certain types of metal castings, drawn, pressed, or cast glass for accurate or scientific use, laundry soaps, high-grade watches, and cheese have had or still have a period of holding somewhere in the process to allow certain changes to take place.

Cylinder blocks for high-grade automobiles used to be rough machined and then stored, often outdoors, for several months to allow strains to equalize before final machining. This is largely unnecessary now because of metallurgical advance in producing this kind of casting. High-grade lathe and planer beds and castings for large surface plates are still aged for months after the rough machining because this kind of equipment must remain highly accurate for years after it is sold and all twist and strain must be equalized before the final finishing.

When the large 200-inch telescope lens for the California Institute of Technology was cast at the Corning Glass Works, it was annealed

for weeks before it was shipped to California to be ground. Since the grinding of the immense mirror's surface involves years of work, the distortion due to grinding away the glass has plenty of time to become less and less as corrections are made by grinding or polishing the mirror's surface.

The Corning Glass Company also draws large quantities of thermometer tubing. For ordinary thermometers any of the mill run of tubing may be used, but for precision work only tubes with uniform bores can be used and these must be aged from six months to one year to allow the tube to become fixed in its dimensions.

Laundry soap stock has always been mixed with fillers and hardening agents in a crutcher. The warm mixture is then poured into a steel box to form a large cake weighing up to 1,000 pounds or more. The semiliquid warm soap congeals and hardens in this large cake in from one to three weeks, depending on the weather. After reaching the proper hardness it is cut into small cakes by pushing the large cake successively through three sets of wires stretched on three frames to make slabs, long bars, and finally small cakes. These are then stamped with the brand name and finally wrapped. The inventory in large cakes runs to enormous sums during the drying period. Today one large company is producing laundry soap from raw material to wrapped bar without the intervening drying period by a new process.

High-grade watches, in the past, were held for a number of days while adjustments for accurate time measurement were made. The more expensive watches used to take a long time to adjust for all the various positions in which they could be carried. The Elgin Watch Company now has a series of specially designed testing machines which print a series of curves on a tape, showing just how much and under what conditions the watch gains or loses. This reading is now made in seconds instead of days. The watch adjuster reads the curves, makes the necessary adjustments and, after retesting, the watch seldom needs further adjustments.

Another group of products are aged after all other operations are completed with the possible exception of final packaging. This group includes certain foods, cheese, liquors, drugs, perfumes, and others. A considerable amount of the difference in quality of many products is due to the changes occurring during the proper aging of the product.

The production of wine, beer, cheese, coffee, hams, and bacon has depended upon proper aging in various stages of their production. Sometimes attempts of science and industry to hasten or to substitute a synthetic aging have been successful, but more often they have

failed because as yet we do not know what happens during the aging process.

One of the major producers of high-grade blue cheese in Minnesota has about 500,000 pounds at all times going through a six months' aging process in sandstone caves. The inventory of this aging cheese cannot be reduced at present unless the quality is seriously impaired or the capacity of the plant is reduced.

Industry is constantly striving to remove the necessity for aging and still maintain or improve on the qualities which age imparts. When and if such innovations can be made further reduction in inventories and capital to finance them will be possible.

Inventory Charges on Carry-Over Goods. At times when inventories of finished goods are carried over from one season to another, there is more than the usual carrying cost involved. The late William M. Vermilye of the National City Bank of New York reported in his *Economic Trends in Manufacturing and Sales* the following example of the cost of carrying seasonal goods over to another season:

A certain corporation, a leader in its industry in the United States, had paid a very satisfactory profit over a period of years and had accumulated a large surplus. This success was based on its superior ability to produce novel and attractive merchandise, and to have a line of goods which, on account of the superior skill with which it was made, gave it a preeminent place. The concern in question made highly styled, seasonable merchandise, and had never used any system of inventory control which enabled it to know how much of its inventory was carried over from one season to the next. The management had the idea that when some of its merchandise was left over from a season and could not be sold except at a sacrifice, it was better to carry it over than to make the sacrifice necessary to sell it, on the theory that the most it could cost them would be six per cent on the amount involved and that after charging this six per cent against the merchandise in question, the goods could still be sold at a better price the next season than if they were forced on the current market. They were more than surprised when I called their attention to the fact that the six per cent which they had figured as the cost of carrying the merchandise over was but a small fraction of what was spent; that in spite of their excellent financial condition, every dollar's worth of idle merchandise which they had on their shelves interfered with the sale of merchandise which should have been active, particularly since in the industry in question an inventory turnover of six times a year was normal with an expected gross profit of about seven per cent. In other words, there was a 42 per cent gross profit per annum to be ex-

pected on the amount of money invested in their inventory, so that if they had merchandise which was idle for six months, it prevented investment of the company's money in merchandise which should have been producing 21 per cent gross in that period; this entirely apart from the six per cent per annum which they figured as the cost of the money employed with no allowance for the cost of insurance, storage or time in effort of the executive and selling departments. Moreover, when the season for selling the merchandise recurred, it constituted an interference with the marketing of the current line for that season, so that in this particular business the cost of carrying merchandise from season to season was much more nearly 50 per cent per annum than 6. And yet, in spite of the company's failure to recognize so perfectly evident and fundamental a condition, the business succeeded for many years. How much more successful it would have been had the executives been able to grasp such a simple principle of economical management!

Inventory, Working Capital, and Profit Relationship. It is evident that profit earned by any business is affected to some degree by inventory turnover. Mr. Vernilye set up a simple equation which shows the general relationship as follows:

Let W = working capital and
 T = turnover.

Then $WT = V$ (volume of business done in dollars).

If P = rate of gross profit per dollar per turnover, then

VP = total gross profit for the business.

If O = the overhead of the business and

P_n = net profit, then

$VP - O = P_n$ or

substituting

$$WT = V$$

$$WTP - O = P_n$$

An increase in net profit can be realized if the working capital is increased, if turnover is increased, if the rate of gross profit is increased, or if the amount of overhead is decreased.

All formulas for analyzing management functions must be examined in a critical manner for current conditions. This formula was developed primarily to show the effect of inventory turnover. It happens to show that an increase in working capital will also increase net profits. But if no increase in working capital is necessary to do a certain volume of business, then increasing the capital will not increase profits. All formulas set up for management purposes should be carefully analyzed by the user to determine if they mean exactly

what they say. While working capital is the basis of this formula it does not necessarily mean that working capital controls the net profit.

The gross profit must be very large in a business where the turnover can only be once per year or less to justify the use of working capital and the payment of ordinary overhead. The most important factor in this equation may be the inventory turnover factor T because it has more possibilities for improvement. Moreover, it often benefits but seldom hampers production.

Banks always press to have the inventories of their borrowing clients at the lowest possible point because so many losses have been due in the past to failure of their clients resulting from a depreciation of inventory.⁴

The banks prefer statements that show slow-moving goods at a minimum. Large inventories of rapidly moving goods are the best security for bank loans because these can readily be turned into cash, especially when they are in the form of finished goods.

Limitations on Reduction of Inventory. On the other hand, one must not forget that to reduce average inventories to a minimum a further investment of capital for additional production facilities often is necessary. The use of these additional facilities may be spasmodic owing to seasonal demand for the product and thus the company would be depending upon partially idle capacity to produce profits. Although inventories are a business hazard, large capital investments in fixed assets can be a much greater hazard because they are subject to various ills which do not affect investment in inventory.

It also is expensive and sometimes impractical to attempt to carry an inventory which will allow immediate service on all customers' orders. By checking the item with the thinking process behind the formulas on page 415, a balance can be struck to determine whether or not the reward in profit is sufficient to justify the expense of the inventory.

Periodic reports to the management as to the current age or condition of all inventories will prevent the accumulation of obsolete or spoiled goods. Some industries manufacture goods which have a limited inventory life. This life may be limited by such things as style factors which are encountered in certain fashionable clothes or fads in games or hobbies. Photographic products such as films and papers have a rather rigid shelf life which determines how long in-

⁴ W. M. Vermilye of the National City Bank of New York, *Economic Trends in Manufacturing and Sales*, p. 18, private printing.

ventories may be held. In most of such inventory life problems it is necessary to remember that the ultimate customer is entitled to a reasonable share of this product life to prevent spoilage during use. Consequently, perishable goods inventories should be most carefully controlled so that quantity on hand is consistent with sales or use and also so that old materials are moved out first.

INVENTORY CONTROL SYSTEMS

Adequate records should be kept of inventory changes to enable the necessary controls to operate. These records should not only be accurate but they must have a minimum time lag to be of the greatest value. The following things can affect inventories and should be reported promptly for accurate records.

1. Material received in stockroom as a result of purchase orders.
 - 1.1 A receiving slip copy or receiving inspection report (see Chapter VII) of each complete or partial shipment should be sent to the inventory control record as soon as possible after the material arrives.
2. Material placed in stockroom as a result of manufacturing orders.
 - 2.1 Either a copy of the official inspection report for the good pieces made or a report of an official count of the product made at the last operation should be delivered to inventory control as soon as possible.
3. Either raw or finished material removed from stock for sale or use should be reported to inventory control.
 - 3.1 Requisitions against stock are often used to release stored goods. A copy of each requisition should be available for posting the inventory record when the material is released or before.
 - 3.11 If material deductions are posted in the inventory record as future orders are scheduled in the plant, *it is very important that the stockroom make no substitutions* when the material is actually issued unless the substitutions are reported to inventory control at once so that the proper credits and deductions can be made on the record.
4. Official inventory counts taken by regular full-time inventory auditors or the usual year's end shutdown for inventory taking sometimes result in changes up or down in the inventory control record.
 - 4.1 If errors are too great or if too many errors are found an analysis should be made to discover the underlying cause.
5. Depreciation and obsolescence of some inventories make it necessary to lower the official count.
 - 5.1 Design engineers should be cautioned to ascertain the inventory status of any part before authorizing the discontinuance of the part.

6. Materials that depreciate in storage owing to limited shelf life or those that can be damaged by poor handling or storage conditions should be carefully analyzed and methods of control set up to eliminate or reduce the depreciation.

The system of inventory control varies considerably in different companies. In general, however, there are three broad classifications of control which are based on:

1. Actual inventory on hand, or order point-reserve stock-economic lot size method.
2. Available inventory for future orders after allocations have been made for all scheduled orders.
3. Accumulated requirements as customer's orders arrive.

The theory of using an actual inventory on hand is based generally on a minimum or ordering point when a new lot to be purchased or manufactured is released. This lot size may be governed by using an economic lot size calculation or chart (see Chapters VII and XX). The point *O* as shown in Figure 1 should be determined by an analysis of the following factors for each material or class of materials.

1. How much of the material is scheduled to be used or sold during the next year or the next production cycle? (The total for the year is often used to iron out the various fluctuations which may occur in some product during the year. However, if the product is not made at all in certain seasons, the amount needed for the next production cycle is the basis for action.)

2. How long, on the average, does it require to purchase or manufacture the material from the time the purchase requisition or manufacturing order is released until the material is delivered to the stockroom? This is known as the lead time and can be obtained from the purchasing or production control records. The lead time is an important factor in determining where the ordering point *O* should be established. Graphically, on Figure 1, the usage line between the ordering point *O* and the theoretical receiving in stockroom point *C* is a part of the usage line *AB*. Theoretically the stock *O* should last until the day the new order is delivered to the stockroom.

The time for procurement of a purchased order usually does not vary greatly with the size of the order unless it is special and needs processing by the vendor after his order is received. In fact, it generally can be considered a constant for any one purchased material.

3. How large should the reserve stock, *R* in Figure 1, be to provide a comfortable safety factor? This reserve is a function of the stock

O_1 in Figure 1, which is normally consumed during the procurement or production time. The consistency of the usage over the production cycle and the possible damage to the prestige of the company or loss of profit if materials were not available when needed are factors in selecting the percentage of the stock O_1 to be used in calculating the reserve stock R .

This reserve stock should be kept as small as possible and it normally is not a function of the ordered quantity Q . From a practical

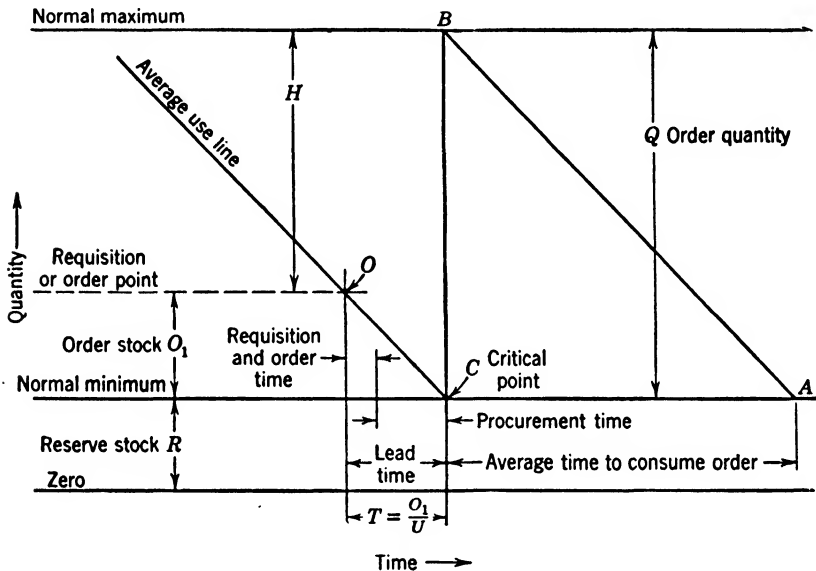


FIGURE 1. Relationships in stock variations.

point it is best set by watching the quantity on hand when the new order is delivered. If the reserve quantity seems to be more than necessary when the new order comes in, it should be watched through several successive new orders; if it continues to be excessive the reserve stock can be reduced. On the other hand, if the stock for any controlled material reaches zero or a dangerous low during a production cycle, the reserve stock should be increased.

If the rate of use varies considerably from month to month, the highest rate of use for any month is a potent factor in the calculation for the quantity O_1 and the reserve stock R .

A sample calculation to determine the ordering point for a given material is shown by the following example:

Material number 12001 has an estimated use at the rate of 12,000 pounds for the next year. It normally takes one-half month to pro-

cure an economic lot size of 2,500 pounds. Occasionally, however, 25 per cent more time is required for procurement. While 12,000 pounds per month is the estimated use for next year, for several months of the past year about 1,200 pounds per month were used. The sales contract for the order which uses material number 12001 has a heavy penalty clause if schedules are not made as planned. Where should the ordering point O be placed, what would be the maximum inventory of stock, and what would be the rate of turnover?

Since
$$T = \frac{O_1}{U} \quad (\text{from Figure 1})$$

and
$$U = 12,000 \text{ pounds per year}$$

$$T = \frac{1}{2} \text{ month} = \frac{1}{24} \text{ year}$$

Then the normal
$$O_1 = \frac{12,000}{24} = 500 \text{ pounds}$$

However, during several months of the year the plant uses 1,200 pounds per month which is 200 pounds over the average. To insure ample stock during the procurement time for periods above average usage, one-half of the extra 200 pounds should be added to the normal quantity O_1 because the lead time is one-half month, or

$$500 + 100 = 600 \text{ pounds}$$

Furthermore, since the procurement time is occasionally 25 per cent more than normal one-half month, the additional usage during the occasional longer procurement time would add another 25 per cent to the quantity O_1 , or $O_1 = 600 + 600 \times 0.25 = 750$ pounds which would be necessary to cover the worst combination of circumstances during the procurement time as stated in the example. The heavy penalty for falling behind the contracted schedule requires that the reserve stock R should be at least 50 per cent of the adjusted usage (750 pounds) during the longest possible lead time.

Then since O_1 after the above adjustment has been increased from 500 to 750 pounds, the reserve stock should be $0.50 \times 750 = 375$ pounds. Thus, when the actual inventory record of the stock falls to $750 + 375 = 1,125$ pounds, a new order for another economic lot should be released. Point C on Figure 1, which may be called the serious expediting point, is where the procurement program for the material must be carefully checked to be sure that it will be delivered in time to avoid the penalty.

If we assume that the maximum time was necessary to procure the new order and that the extra quantity for a big month had been used, then the low point of 375 pounds would have been reached when the new lot of 2,500 pounds was delivered to the stockroom. Thus the maximum inventory record of stock would reach 2,875 pounds theoretically. The rate of turnover at the average use of 1,000 pounds per month would be $12 \div (2,875/1,000)$ about four times per year.

By adding the abnormal requirements of the example to the quantity O_1 the reserve stock is kept down because the date of the release of a new order is pushed forward. In other words, instead of a lead time of fifteen days, the adjusted lead time to cover the abnormal conditions was increased to about twenty-three days. By releasing a new order earlier, the chance of increasing the inventory by earlier delivery was less than having the inventory definitely increased by a larger reserve stock to take care of the abnormal conditions.

There are a number of possible forms used to post the information for a perpetual record of the material on hand. The most simple one is a bin card similar to the one shown in Figure 2. The bin card is posted by stockroom personnel as stock is received or issued. The card is usually placed on each bin or storage place and the stockroom personnel is supposed to record each transaction as it occurs. In the example shown, $11\frac{3}{4}$ gallons of S.A.E. motor oil #40 were on hand July 11, 1948. The various issues are charged against budget numbers as sold or issued. The new balance is calculated by the stores attendant. When new stock is received, it is added to the stock on hand to get the new balance. This sort of record is not considered good enough for accurate control and is of little or no value for cost accounting purposes.

Quantity 11 3/4 Gal Inv. No. 17174
Article #40 S.A.E. Motor Oil
From M^{rs} Glynn Unit _____
Date 7/11/48 Order No. B10941

DATE	BUDGET	SOLD	BALANCE
7/12/48	No 20	1/4	11 1/2
7/15/48	Mn 3	1 1/2	10
7/15/48	M.O	1	9
8/1/48	M2172	1	8
8/14/48	Delivered		48
			56

(178)

FIGURE 2. Simple bin card.

The primary purpose of the stores personnel is to receive and issue the various materials, largely a labor function. It is usually unwise to ask this type of personnel to perform a comprehensive clerical function in addition to regular duties. Even though the bin card will work in simple cases, it is not a recommended method.

The actual inventory on hand method of controlling inventories does not provide the best results where the use of materials varies widely in different periods or where inventories are carried for intermittent current production only. If the reserve stock or the ordering point has to be adjusted too often or if the quantity of inventory on hand is too high during low usage, the method of inventory control should probably be changed to one that is more adaptable to large fluctuations in demand.

The allocation method of inventory control is illustrated in Figures 3 and 4. This method does not depend on an order point but on the needs for each material as shown by the projected shop schedules. Well-organized plants know their requirements in advance so that the future needs can be posted as an allocation against that part. When these allocations reduce the *available* balance below a safe point, as measured by the quantity needed on certain dates, a purchase or manufacturing order is released in time to arrive in the stockroom by a definite date.

The inventory status of part number 15526, which is controlled by the allocation method, is shown in Figures 3 and 4. The physical inventory on January 8 as shown in Figure 3 was 15,500. From this date, each order released for the part is subtracted from the balance available and also is added to the total used to date. Enough releases were issued to reduce the balance available to a negative 9,551 on January 24. On January 24, manufacturing order number 20066XV155, issued January 2, which originally called for 3,000 pieces, was delivered to the storeroom. However, 3,250 pieces were actually delivered to reduce the deficit of 9,551 to 6,301 pieces. The manufacturing order numbers and amounts ordered and received are entered at the top of the card. When more than the original order is delivered, the balance due is credited only with the number ordered to prevent negative amounts appearing in the balance due.

The records shown in Figures 3 and 4 are usually posted and filed in the production control office so that the planning section can quickly ascertain if materials or parts are available for future orders or if purchasing or manufacturing orders must be issued to prevent stock shortages for future orders.

[illegible]

FIGURE 3. Inventory record card to show available balance as new orders call for stock.

[illegible]

FIGURE 4. Opposite side of card shown in Figure 3. Record is continued on this side.

As the materials or parts are completed or delivered to the stockroom, the quantity and its original order number are entered in the proper columns and a cumulative total is taken for each delivery. When the invoice or manufacturing cost arrives, the cost accounting department makes the proper entries to determine the unit cost value at the bottom of the card.

[illegible]

The materials or parts are issued against the work order which uses them. The accumulated sum of the quantities issued is subtracted from the sum of the quantities received to get the balance on hand. The value of the inventory at any time is the product of the balance on hand and the latest unit cost value.

Figures 6 and 7 illustrate a simple inventory control record which is valuable for many plants manufacturing a number of products with the same machines. This card is printed on both sides with space for sixty-eight transactions on the card, since only one transaction is written on each line. The reserve factor, order point, and economic lot size are calculated for each part. (See pages 417-422.) If a casting is used for part number 7501, it can be designated by part number 7501M. When machined, the casting becomes part number 7501. However, to distinguish between the casting and the machined part for inventory control purposes, it is better to give it some extra symbol such as the "M."

[illegible]

FIGURE 7. Simple inventory control record for job lot plants.

If it is not always expedient to machine all the castings in one lot, the stored castings will be clearly recorded as castings and not be confused with machined parts.

The minimum run is set at 50 units to prevent the setup cost per unit from being excessive.

The total used last year shows that the use of the part has been rather stable for some time. Card No. 1 for 1948 merely shows the number of card faces used during the year. Each card has two faces.

The number used and model indicates how many parts are used for each machine model produced. If any great amount of standardization has taken place in a plant with many models of machines, this space may not be large enough.

The quantity ordered may refer to the quantity of castings, parts, or materials purchased or it may be used to record the number to be made on a manufacturing or shop order. In either case the figure is placed in the quantity ordered column, and the purchase order number or manufacturing or shop order number is placed in the reference number column. In addition the reference number column is used to record the manufacturing or shop order number under which finished parts, materials, or raw castings were issued for assembly or machining. The date column is used for every transaction to show when it occurred.

The series of postings from the 1/5 inventory entry in the balance on hand columns for both 7501 and 7501M to the 4/10 posting on 7501 will show how this record works.

Both cards had inventory posted on 1/5 as 0 for card 7501M and 152 for card 7501. These inventory figures are generally posted in color (say green) to show clearly an occasional actual inventory count as a check on the record.

Twenty parts were issued on 1/10 for manufacturing order number 784, which reduced the balance on hand to 132 and set the used balance at 20 for the new year. Since 132 is under the order point of 140, a purchase requisition for 280 number 7501M castings was written by production control upon notification from the inventory control clerk. (See Figure 6.) At the same time that the requisition for the castings was written, production control also prepared the forms to release the manufacturing order for machining the castings. (See Chapter XXIII.) The manufacturing order forms along with the latest print of the part are filed until the castings arrive in the plant. (See Chapter XXIII for procedure after castings arrive.)

Simultaneously the purchasing department sends a purchase order, number 15783, to the foundry and a copy (among others) to inventory control. The quantity ordered, the date of purchase, the purchase order number under reference number, and the balance on order are all posted by the inventory clerk as shown in the date line 1/10.

Fifty parts were issued on January 16 for order number 801 to reduce the balance on hand to 82 and to increase the used balance to 70.

On January 23 the receiving department reported the arrival of 286 castings against the order for 280. The inventory clerk's copy of the receiving slip was the authority to post as shown in the 1/23 date line. Note that the balance on order cannot be a negative quantity even if the amount delivered is greater than the amount ordered.

Production control's copy of the receiving slip shows that the castings are in and can be machined according to the schedule previously planned for them. (Manufacturing orders are not released until the material is on hand.) Since there are usually some pieces scrapped on this part the 286 castings were ordered moved to the first operation to start manufacturing order number 893 for 280 pieces. (See operation sheet on page 222 to see how this can be done.)

Inventory control's copy of the manufacturing order 893 is authority to post part numbers 7501M and 7501 as shown on the 1/24 date line.

Part number 7501 had two issues as shown on the date lines 1/25 and 2/1 before manufacturing order 893 was delivered to the stockroom as posted on the date line 2/3. Note that just before the new order of pieces was delivered the balance on hand was down to 37 pieces which was quite close to the reserve of 35 pieces. The reserve should be checked often at the time of incoming stock to see if it is too large or too small. Either one is undesirable. If the reserve is too large, the inventory is larger than necessary; if too small, schedules may be seriously upset.

The Minneapolis-Honeywell Regulator Company's inventory record for productive materials is illustrated in Figure 8. This record is machine posted to record a series of transactions to order, receive, assign, release, and issue the materials for production.

Purchase orders are issued by the purchasing department upon receipt of a purchasing requisition from production control (see page 401 and Figure 19 of Chapter XVIII). When the production control copy of the purchasing order arrives it is the authority to post as shown for July 11. The "PO" entry and number 56869 refer to purchase order number 56869.

The code number in all posting is only to record the transactions on the daily tape duplicate of all transactions so that any mistakes can be found readily from the original postings. Note that this number is used only for each day's postings and the number is always the same as the number 27380 in the upper right corner.

The purchase order quantity of 2,500 pounds is written on the date line of July 11. This creates an on order balance for 2,500 pounds. (During the difficult postwar material shortages these on order post-

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FIGURE 8. Inventory record for controlling the ordering, receiving, assigning, releasing, and issuing of production materials.

FIGURE 8. Inventory record for controlling the ordering, receiving, assigning, releasing, and issuing of production materials.

ings are recorded in greater detail as in Figure 20 of Chapter XVIII to insure a closer check on deliveries and vendor's delivery promises.)

Order number 56869 was received and accepted on July 15 under the reference column "Rc" and the original purchase order number. The quantity accepted (2,340 pounds) increased the balance on hand to 238,440, the available balance to 227,921, and the release balance to 227,929. However, since only 2,340 pounds of the 2,500 pounds ordered were received, a purchase cancellation of 160 pounds was also entered on July 15 to reduce the on order balance to zero.

Material use is accounted for in three steps: (1) assigned, (2) released, and (3) issued. These three steps may be weeks apart or they may all happen in one day. (See page 429.) If all steps are completed at once, the transaction is the same as any less-exacting inventory control method where a material is issued in one transaction when it is taken from the raw material stockroom.

In the necessarily complicated control described here where many parts may be made from one material, the material is assigned when the part is first planned for the production program. Part number 35010 entered for job number 46840 on July 10 illustrates how only 8 pounds of material were assigned. The total assignments of all job orders written on July 10 was 10,519 pounds including the 8 pounds for job order 46840. This assignment of material reduced the balance available to 225,581 pounds from the July 1 inventory figure of 236,100 pounds. All the job numbers written on July 10 had their materials assigned and released on the same day except job number 46840. Since the 8 pounds for this job number were not released, the release balance at the close of the day on July 10 was 8 pounds more than the available balance. Note that the material for job order 46840 was still not released by July 16 when this record was obtained.

Only part number 13272, among the others which had their materials assigned and released on July 10, had its material finally issued on this record (July 16). However, only 160 pounds were actually issued which reduced the on hand and the releases unfilled balances by 160 pounds each. The 2 pounds not released for job number 45144 show as a cancellation in the release and assigned columns, which increases the available and release balances by 2 pounds and reduces the releases unfilled balance by 2 pounds.

On July 16, 950 pounds were assigned and issued for a nonproduction work order number 1068. This transaction reduced the available and the on hand balances by 950 pounds but did not affect any of the release columns.

The data for posting the material control ledger consist of purchase requisitions (see Figure 19, Chapter XVIII), receiving and inspection tickets, and the several types of requisitions which will be discussed in Chapter XXIII.

Physical Inventories and Methods. For official purposes, such as taxation and determination of profit and loss, it is necessary occasionally to check the inventory records by a physical count of all inventory. Errors in the book values and suggestions for preventing such errors in the future can result from periodic checks. Many concerns have developed systems of control and record keeping which consistently agree with physical inventories within close limits.

The thorough physical inventory should be made while the entire plant is closed and all material movement is at a standstill. This, however, is expensive and many plants have substituted a perpetual inventory audit technique which often is better than the old "stop production" method. A trained squad of inventory auditors are used to check continually inventory record balances with a physical count. By this method every inventory item is checked at least once a year. However, once a quarter or once a month would be better for many fast-moving items. When this plan of official counting is used it is essential to have the cards with the official counts flow to the inventory control file as quickly as possible for fast-moving materials. In other words, the inventory count and record should be compared as soon as possible so that storeroom transactions in between cannot affect the accuracy.

This procedure has been criticized because the entire inventory at a given time is not checked by physical count. However, if records and methods of keeping them are developed by an analysis of past errors, the continuous auditing method of checking inventory will give as good if not better results than the old hurried system where a large number of inexperienced persons are used for physical counting.

Figure 9 illustrates a form which was accepted by a large New York certified public accounting firm as a part of a system for taking continuous inventory. The inventory audit card was partially prewritten by filling in the part number, part name, and location. The location was important because if the parts were stored at more than one place the several counts for the part had to be made simultaneously to get the exact total number at any given time.

This approach focused attention on methods of storing and the reduction of places used for storage. The inventory was counted several times by this procedure, the stockrooms were arranged better, and no stock was stored in more than two places. Generally the retail stock

was centrally located while the wholesale stock, if any, of the same article was stored in a convenient warehouse. The wholesale stock was stored in sealed packages if possible which had been precounted. When the retail stock was replenished from the wholesale stock a sealed package or a fixed number was moved to the central storeroom.

The partial prewriting of the inventory audit card provided a program for the counters every day and insured an orderly procedure for covering the entire inventory during the selected period.

The detailed inventory audit procedure was outlined as on page 433 to aid the involved personnel.

INVENTORY AUDIT CARD NO. 28309	Part Number <u>12961</u>	INVENTORY AUDIT CARD NO. 28309	Part No. <u>12961</u>
	Part Name <u>Tubing - Derr. Drive Roller</u>		Time & Date <u>3:10 PM - 6/8/47</u>
On Hand <u>291</u> Unit <u>pcs.</u>	Time & Date <u>3:10 PM - 6/8/47</u>	Part Name <u>Tubing - Derr. Drive Roller</u>	
Inventory Auditor <u>J.A.C.</u>		Quantity on Hand <u>291</u> Unit <u>pcs.</u>	
		Location <u>Storeroom</u>	
		Also Stored at _____	
		Inventory Auditor <u>J.A.C.</u>	

FIGURE 9. Card used for recording a continuous inventory taken by trained personnel.

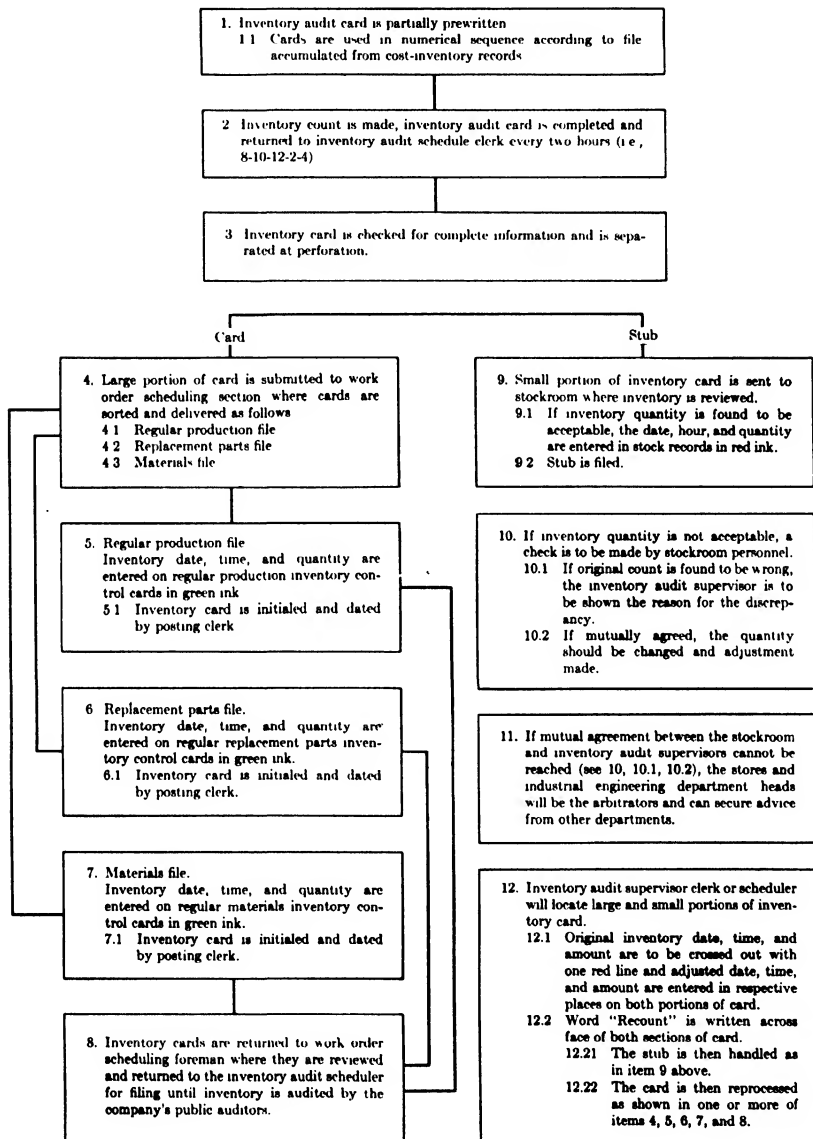
The inventory was counted four times per year at first until the plan proved that the inventory control record was functioning properly. Later the counting cycle was reduced to two times per year and thus has been continued with no annual shutdown to take the usual physical inventory.

A cost analysis was made to determine the relative costs of the inventory audit versus the annual physical inventory methods and it was found that the inventory could be counted four times per year by the inventory auditors or professional counters method for less than was expended for the regular annual physical count. In addition production was not stopped and thus the plant's capacity to produce was increased by almost 2 per cent. When the counting cycle was reduced to two times per year the financial advantage was still more favorable towards the inventory auditor method.

The benefits of the inventory auditor method also extend to the stockroom. The system focuses attention on faulty stockroom techniques which can be corrected as they are found.

Organization for Inventory Control. The responsibility for the control of the quantity of materials in inventory may be placed with the

INVENTORY AUDIT PROCEDURE



purchasing, accounting, or storekeeping departments or with the treasurer, but by far the most common place for this control is with

the production manager who usually is responsible to the chief manufacturing executive. The production manager is usually selected for this responsibility because he is charged with all manufacturing processes and costs thereof, as well as quantity and quality of the products. Since materials and their availability are so closely connected with these problems of manufacturing, the production executives need the authority to control the flow of materials if they are to have the responsibility of producing them. However, no wise production manager consistently opposes the advice and assistance the purchasing and treasury departments can offer for a more efficient use of capital in maintaining inventory.

It often has been argued that the accounting division should have the duty of maintaining the stores and stock records. It is true in the final analysis, when costs are recorded, that the accounting department must keep the books of the establishment. In practice, however, it is not always feasible to have the accounting division keep the records of quantities and rate of flow which are primarily for the use of the production control department. The relationship between the inventory record clerk and those responsible for planning the work in the shop is immediate and compelling. Therefore the best place for such record keeping is in the production control department with only a general supervision from the accounting division to provide the proper coordination between the two departments.

PROBLEMS AND QUESTIONS FOR DISCUSSION

1. How does improved transportation service reduce inventory costs?
2. Study the annual report of any major manufacturing company and compute the turnover for the business as a whole.
3. Why is this turnover figure in Problem 2 unsatisfactory as an operating control?
4. Discuss the various costs incurred by carrying inventory.
5. What effect would the purchase of only national coarse or national fine screw threads for all screws have on inventory costs? Why?
6. Should inventory costs be considered in the purchase of goods? Why?
7. Name ten products which now require large variations in inventory. How would you eliminate some of the seasonable aspects of such inventories?
8. How far can improved methods go towards reducing inventory?
9. Discuss ways and means of reducing losses from depreciation, shrinkage, and obsolescence of stored materials.
10. A firm has a working capital of \$10,000 which is needed to replace necessary materials and purchased finished parts each month. Each month's business averages about 3 per cent gross profit. If the firm would like to

earn a net profit of 10 per cent, what are the limits of the amount which can be spent for overhead charges?

11. If business increases to allow fifteen turnovers per year and overhead is the same as in Problem 10, what is the net profit percentage?

12. If business decreases to three turnovers per year, what must be done to maintain net profits at 40 per cent of the amount in Problem 10?

13. Why should inventory records be kept in the production control office?

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CHAPTER XX

ECONOMIC LOT SIZES

Setup for Lot Production. The number of pieces, pounds, or gallons to be made in one manufacturing order has a definite effect on the ultimate cost of production of most products. Where handcraft methods of processing are used, the cost of changing from one job to another is often negligible. However, in modern production methods, the cost of setup, cleanup, and general change-over operations for a new manufacturing order usually costs more than a few units can absorb economically. This setup time may vary from a few minutes for such machines as simple drill presses, sewing machines, and bottle cappers to a total of over one thousand man-hours for the complicated automobile frame machine of the A. O. Smith Company. This frame machine requires about two hundred men for eight hours or more to change from one type of frame to another. However, once set up, it machines the frame members, assembles, washes, enamels, and delivers a complete frame to the stockpile every eight seconds. This is at the rate of 10,000 frames per twenty-four hours.

Obviously, a large number of automobile frames must be completed on this machine between setups to keep the setup cost low per unit. The larger the manufacturing lot, the smaller the change-over charge becomes for each unit of product.

Setup for Mass Production. The ultimate in low setup cost per unit is reached in the continuous- or mass-production plants where the product is processed over the same machines for months and even years without changing the setups. However, the problem of economic lot size does not arise because the parts or products are planned to be produced only as fast as needed. The normal variation in parts inventory, so necessary in lot manufacture, is unnecessary in continuous manufacturing. In mass production, individual finished parts are seldom carried in stock. They are carried as process inventory from one machine to the next and delivered to the proper point at the proper time in the required number to produce the finished article.

JOB LOT COSTS

Owing to limited or seasonal demand, style factors, variety of products, and higher productive capacity than can be consumed continuously, many industries must use the lot manufacturing method. For this type of plant it may be wise to consider a control of the lot size to insure minimum ultimate cost per unit when all pertinent costs are included.

If only the manufacturing cost is considered, a narrow-minded production executive may advocate the production of large lots to get the lowest unit cost. On the other hand an equally narrow-minded financial executive may advocate small lots to keep down the capital invested in inventories and thereby increase the inventory turnover. Both executives are correct in their reasoning, but both may be wrong in the ultimate analysis of cost. There is an economic balance between these two extremes which can be studied mathematically to avoid the errors involved when the lot size is set haphazardly.

The economic errors at the extremes of very small or very large lot sizes are so obvious that most factory executives would have no difficulty in recognizing them. The greatest danger lies in the less obvious errors. Lot size quantities which do not look at all absurd may yet be far enough away from the ultimate minimum unit cost to increase the final product cost.

How to Detect Poor Lot Sizing. Often a clue to poor lot size determination is the frequent use of certain round numbers for many parts. Lots of 1,000 or 10,000 units are used quite often where no specific calculations are made. Round numbers may be used even where economic lot sizes are determined by analytical means. Figure 2 shows that the curve is quite flat on both sides of the economic quantity. However, round numbers selected as the result of an analytical method will probably be expressed in a large group of round numbers rather than a few. Other quantities such as those which will keep a mechanic busy for one day or for one pay period may be used. Sometimes the quantity of parts which may be held in one tote pan, truck, or skid platform is the basis for the lot size. Lot sizes selected by such methods should be questioned and studied with a special calculation or chart for that product.

Theory of Economic Lot Sizes. The economic balance between the low unit inventory charges and low unit preparation charges, obtained by short and long runs respectively, lies somewhere between these two

extremes. Professor F. E. Raymond¹ states that this balance is achieved when the unit preparation costs are equal to the unit costs incurred by the inventory of any material. This is demonstrated on page 445. The ideal cost for manufacturing operations is the combination of costs which consistently allows the product to be delivered to the customer for the lowest price f.o.b. factory. This definition of ideal cost must, then, necessarily include the labor, material, overhead, setup, and inventory charges in such proportion that the sum of these is a minimum.

There are variations in the emphasis applied to the different factors which may be included in the ideal economic lot size calculation. If all these variations were entered into the mathematical analysis, the resulting equations may be so complex that it would be uneconomic to use them.

Space Charge. The danger always exists, if formulas are too general, that items will be included which have no bearing on the case being studied. For instance, most general formulas include a space charge for storing parts as a part of the inventory charge; but one should know how the space charge is calculated before using the formula blindly. If space is at a premium and released space can be used for other purposes, then space requirement differentials become economically valuable and should be considered. However, if released space is not used for other purposes or if the total released space is not sufficient to, say, close off a room or floor and thus save on heat, light, and other services, nothing is saved by such release. Obviously, a saving in space which cannot be profitably used for other purposes is no saving at all and should not be included as a factor in the formulas used. Some formulas base the storage on the average number of pieces in storage. If a bin or floor space has been assigned for the storage of a unit, often it is not feasible to constrict the storage space as the inventory decreases. Thus the charge for storage space should include the space needed for the maximum inventory. This includes the quantity delivered to stores as well as any reserve stock held for emergencies. If the space released as the stock inventory is reduced can be profitably used for other purposes, then the average stock inventory can be used for calculating the storeroom charge.

Obsolescence Charge. Economic lot size formulas generally cannot include factors for obsolescence because of sudden changes in styles or models. Where such changes are common the inventories must be

¹ *Quantity and Economy in Manufacture*, F. E. Raymond, McGraw-Hill Book Co., 1931.

carefully controlled at all times to prevent loss. It is better to keep inventories at low levels and to absorb a higher unit preparation cost in the product than it is to have large stocks of parts depreciate in value if and when they become obsolete.

Interest Charge. Most formulas for economic lot size include an interest charge for carrying the inventory. Often, however, this interest charge is the same as the current rate for loans. This amount is generally lower than the average earning power of the business. The added risk of business ventures over ordinary banking should permit the use of an additional charge above simple interest for the use of capital to carry inventories. (See Chapter XIX, page 414.) If 3 to 4 per cent is the current rate for interest on business loans, to this should be added the normal return earned by other capital in the business. The business risks, for capital in inventory, brought about by material price changes, obsolescence, depreciation, and other unforeseen losses can be as great as other risks in business. Consequently, an allowance should be included in the economic lot size calculations to recognize this risk and increase the rate of inventory turnover.

It should be pointed out, however, that if this normal rate of capital return is added to simple interest the total cost of one year's supply represents a theoretical something added to the true manufacturing cost of material, labor, and overhead. This will usually increase the apparent inventory carrying charge of the manufacturing lot; but since manufacturing is only one of the several major costs in business the principal concern is to make the sum of all costs as low as possible.

Preparation Cost. The problems involved in arriving at the preparation cost often include a number of details. Since this cost is generally repeated each time a new lot enters the factory, it is essential to study it carefully. The cost of setting up the office equipment necessary to produce the forms for a manufacturing order, the labor to prepare the information and to duplicate the forms, the distribution of these forms to the proper locations in the shop, and the proper amount of the production control department overhead constitute the paper preparation cost. In some shops this work is done by superintendents, foremen, clerks, and other indirect workers in the shop and is thus included in shop overhead cost. Determination of manufacturing order paper preparation costs is much more difficult where it is not done from a central organization.

Additional preparation costs, such as machine setup, getting materials, tools, blueprints, and sometimes waiting for jobs, should be carefully studied to determine the cost for these operations in the shop.

Generally the gathering together of the various things used for an operation is more expensive if the mechanic is required to do it. Not only is his wage rate higher than necessary for this type of work, but also the machine is idle while the mechanic is doing the gathering. Moreover, the foreman's time is often used to aid the mechanic in getting ready for a job. The foreman's time usually is a shop overhead item, but if he aids in doing the setup operation it should be added to the preparation cost. Such an analysis of preparation cost often throws light on absurd conditions which need correcting.

Reserve Stock. The problem of reserve stock is not so critical for manufactured orders as it is for purchased orders. (See Chapter VII, page 108.) When the material is being made in the plant, the chances of getting the material when needed are usually better than when the material is purchased from outside vendors. In some plants, the inclusion of the cost of carrying the reserve stock for calculating the economic lot size is not necessary. However, if the manufacturing process is precarious or unpredictable the cost of carrying reserve stock may be large enough to warrant including it in the formula. A few test cases in any one plant will determine if the extra cost should be added.

The selection of the proper factors to include in an economic lot size formula will vary with the product and plant. Consideration should be given to the following points and decisions made to use or discard them as a few sample calculations will disclose.

1. Should simple interest be charged on average inventory value?
 - 1.1 Use rate paid by company for business loans.
2. Should normal return from other capital invested in the business be expected from average investment in inventory?
 - 2.1 Consider average return on capital during some period, say for the past five years. This procedure tends to reduce the economic lot size and thus decreases the investment in inventory.
3. Should insurance and tax charges in percentage be added to the simple interest rate?
 - 3.1 Some states do not charge taxes on materials in inventory.
4. Should storage space charges be based on maximum or average inventory for any given material?
 - 4.1 Can the difference between average and maximum space requirements be used economically in between the periods of low and high inventory?
5. Is the necessity for and size of the reserve stock factor potent enough to include it in the formula?
 - 5.1 A few sample calculations will disclose this.

6. Are seasonal changes in demand large enough to warrant breaking the years into quarters so that the calculations can be closer for current demands?

6.1 This would mean that the basis for calculations would be by the quarter rather than for the year.

Development of Formulas. Many formulas have been devised to fit specific needs, but this text does not advocate the use of any one formula. F. E. Raymond² develops the subject of economic lot size very completely to include general formulas and a number of variations of the general form. The serious student of economic lot size should study this excellent reference volume. Professor Raymond's book discusses the large number of variables which can affect the size of the manufacturing order. Some of these variables become insignificant, however, under certain conditions and need not be considered.

A method which can be used to derive a simple formula³ is shown below. Let

Q = economic lot size.

P = number of pieces actually produced per day.

M = average number of pieces used per day.

C = cost per part including material, labor, and overhead, but not setup cost.

A = cost of setup and all other preparation costs chargeable to this lot. (See page 440.) If setup time is long and *plant is running near capacity*, this item should include loss of profit from machine during setup time.

I = sum of annual rates (in decimal form) of interest, insurance, return on investment in inventory, and taxes. (See pages 109 and 440 for discussion on interest rates for this purpose.)

R = reserve stock, which is the number of pieces or quantity in stock when the new lot enters the finished inventory. It is purely a safety factor and is often set as a percentage of the amount used during the manufacturing cycle. (See page 441.)

S = storage charge per unit per year. (See discussion of storage charges on page 439.)

N = number of days worked per year.

Y = total cost of one year's supply.

² *Quantity and Economy in Manufacture*, F. E. Raymond, McGraw-Hill Book Co., 1931.

³ Adapted with changes from a discussion in *Economic Control of Engineering and Manufacturing*, F. L. Eidmann, McGraw-Hill Book Co., 1931, p. 245.

The quantity on hand at any time varies from zero (depending on how much of the reserve stock is used before the new stock is ready) to $R + Q$ or less as a maximum, depending on how fast the parts are used compared to how fast they are produced. If the unit part can be made many times faster than it is consumed in the final assembly, then almost the whole lot will probably be placed in storage along with the reserve stock R . However, if the parts are made, say, only 25 per cent faster than they are used, then the number of parts to be stored will be considerably less than the number of pieces in the lot.

Thus the quantity of finished pieces on hand in the stock room can vary between

$$R \quad \text{and} \quad R + Q$$

if no parts are used while the part is being made. When parts are used while they are being made, the average stock on hand is

$$R + \frac{Q(P - M)}{2P}$$

because $(P - M)$ pieces are made in excess of the daily requirements each day. The lot requires Q/P days to complete the order; during this time the quantity on hand above the reserve stock may vary from zero to the maximum amount delivered to stock when the order is finished. The average stock on hand, of course, is half the maximum.

The manufacturing cost per unit including labor, material, overhead, setup, and preparation cost is

$$C + \frac{A}{Q}$$

Thus the average investment in the process and finished inventory is

$$\left(C + \frac{A}{Q}\right) \left[R + \frac{Q(P - M)}{2P}\right]$$

The simple interest, insurance, taxes, and return on capital invested in inventory per year on this average investment are

$$I \left(C + \frac{A}{Q}\right) \left[R + \frac{Q(P - M)}{2P}\right]$$

The storage charge per year, if any (see page 439), usually is

$$S \left[R + \frac{Q(P - M)}{P}\right]$$

because storage space can seldom be assigned below the maximum requirements.

The total cost of one year's supply is the sum of the manufacturing costs plus the storage charges of the maximum amount of material in storage and the various charges on the average inventory value.

$$Y = NM \left(C + \frac{A}{Q} \right) + I \left(C + \frac{A}{Q} \right) \left[R + \frac{Q(P - M)}{2P} \right] + S \left[R + \frac{Q(P - M)}{P} \right] \quad (1)$$

$$Y = NMC + \frac{NMA}{Q} + ICR + \frac{ICQ(P - M)}{2P} + \frac{IAR}{Q} + \frac{IA(P - M)}{2P} + SR + \frac{SQ(P - M)}{P} \quad (2)$$

Y is a minimum when $\frac{DY}{DQ} = 0$.

$$\begin{aligned} \frac{DY}{DQ} &= -\frac{NMA}{Q^2} + \frac{IC(P - M)}{2P} - \frac{IAR}{Q^2} + \frac{S(P - M)}{P} \\ \text{or} \quad \frac{NMA + IAR}{Q^2} &= \left[\frac{IC + 2S}{2} \right] \left(\frac{P - M}{P} \right) \\ Q^2 &= \frac{2NMA + 2IAR}{(IC + 2S) \left(1 - \frac{M}{P} \right)} \\ Q &= \pm \sqrt{\frac{2NMA + 2IAR}{(IC + 2S) \left(1 - \frac{M}{P} \right)}} \quad (3) \end{aligned}$$

The charge for the reserve stock ($2IAR$) in equation (3) often can be neglected. Unless the necessary reserve stock is unusually high it does not affect the economic lot size appreciably. If sample calculations show that the added complication does not change the result more than a few per cent, the reserve stock for that plant or department is not important. Equation (3) can then be simplified to

$$Q = \pm \sqrt{\frac{2NMA}{(IC + 2S) \left(1 - \frac{M}{P} \right)}} \quad (4)$$

Sometimes the storage factor can be neglected also if the parts are small or if the storage charges per square foot are small. Sample calculations will quickly show if it is negligible. If the storage charges prove to be insignificant, equation (4) can be further simplified to

$$Q = \pm \sqrt{\frac{2NMA}{IC \left(1 - \frac{M}{P}\right)}} \quad (5)$$

If the inclusion of all factors does not change the lot size more than a few per cent, the extra complication is not warranted. It is seldom possible to be sure that the data are accurate to within several per cent. Thus striving for absolute accuracy in any economic lot size calculation is rather foolish.

Equation (4) can be used to show that unit preparation costs are equal to the unit costs incurred by the inventory of a part if the economic lot concept was used to calculate the size of the lot. (See page 439.) If costs for storage, interest, and other charges against inventory are isolated from preparation costs, equation (4) becomes

$$Q = \pm \sqrt{\left[\frac{2NM}{(IC + 2S) \left(1 - \frac{M}{P}\right)} \right] A}$$

Then let H = unit inventory charges on the stored material.

$$H = \frac{(IC + 2S) \left(1 - \frac{M}{P}\right)}{2NM}$$

Thus $Q = \frac{A}{H}$

or $HQ = \frac{A}{Q} \quad (6)$

This relationship is a simple way to make a series of test calculations to find the economic lot size by the tabular method. The following example will be used to illustrate three methods of finding the economic lot size.

EXAMPLE OF ECONOMIC LOT SIZE CALCULATIONS

Part 983, which is a complicated screw machine product, is used at an average rate of 1,000 pieces per day. It can be made at the rate of 2,500 pieces per day. The plant works 300 days per year. The preparation and setup operations for this part cost \$46. The factory cost of material, labor, and overhead per part is \$0.153. The volume of the part is small but storage will be calculated separately to show its significance. The storage cost per unit per year is \$0.0015. The part is important in the assembly of the daily quota of the final product so that a reserve stock of at least ten days' supply must be on hand at all times. The current rate of interest for business loans is 4 per cent with insurance and taxes at 2 per cent. Capital invested in this business earned 16 per cent last year. What is the economic lot size for part 983 under these conditions?

Tabular Method. Table 1 shows how equation (6) may be used to solve an economic lot size problem by the tabular method.

TABLE 1

$$H = \frac{(\$0.22 \times 0.153) + (2 \times 0.0015) \left(1 - \frac{1,000}{2,500}\right)}{2NM} = 0.3666 \times 10^{-7}$$

Q	HQ	A/Q
1,000	0.00003666	0.046
10,000	0.0003666	0.0046
20,000	0.0007332	0.0023
30,000	0.0010998	0.00153
35,423	0.0012986	0.0012986
40,000	0.0014664	0.00115
60,000	0.0021996	0.00077
100,000	0.003666	0.00046

Table 1 at 30,000 units indicates that A/Q is slightly larger than HQ . However, at 40,000 the reverse is true. This indicates that the economic lot size lies somewhere between 30,000 and 40,000 units. By a persistent cut-and-try method the exact balance can be found at 35,423 units.

Formula Methods. By using equation (4) for the same example

$$\begin{aligned}
 Q &= \pm \sqrt{\frac{2NMA}{(1C + 2S) \left(1 - \frac{M}{P}\right)}} \\
 &= \pm \sqrt{\frac{2 \times 300 \times 1,000 \times 46}{[(0.22 \times 0.153) + (2 \times 0.0015)] \left(1 - \frac{1,000}{2,500}\right)}} \\
 &= \pm \sqrt{\frac{27,600,000}{0.021996}} = 35,423 \text{ units}
 \end{aligned}$$

If the more complicated equation (3) is used to calculate the same example, the answer of 35,435 units is so close (0.034 per cent) to the more simple equation (4) that the ordinary slide rule could not detect it. Thus the reserve stock factor $2IAR$ in this example is not important.

However, if the storage charges ($2S$) are also dropped as shown in equation (5), the lot size is *increased* to 36,967. This is 4.3 per cent over the quantity calculated by equation (3). It is well to remember that, when storage charges are dropped, the lot size is always increased to some degree, which means that more working capital is necessary to carry the increased inventory. The storage charges are usually more significant than the reserve stock charges, particularly if the storage charges are high per unit.

In this example the actual lots to be manufactured can be rounded off to 35,000 for equation (4) and 37,000 for equation (5). The selected economic lot size of 35,000 units, where all significant charges are included, is large enough to last the assembly department about thirty-five days for each setup for part number 983. The process time for this lot is about fourteen days.

Chart or Nomograph Method. A third method based on equation (5) is shown in Figure 1. This chart is easy to use and provides the answer to either the economic purchasing quantity (see Chapter VII) or the economic lot size for manufacturing, and the ratio A/C is the only calculation necessary.

Unless the storage charges are large enough to warrant using equation (4), this chart greatly reduces the labor of calculating the various steps of an economic lot problem.

The series of many parallel oblique lines are used for the various number of units of any given part or material used per year (NM). The ratio A/C which is the setup cost A over the unit cost C is shown across the scale on the bottom. It ranges from 1 to 1,000. The economic lot size as determined by equation (5) is shown across the scale on the top. It ranges from 100 to 100,000. The five oblique lines cutting across the entire chart are used as a turning point for the operation of the chart. To select the proper line from the five available depends on the value of $(1 - M/P)$. If few or no parts are used during their manufacturing cycle, the lower line of the five is used. If $(1 - M/P)$ is 0.6 the middle line of the five is used.

The lowest of the five oblique lines discussed above is based on inventory charges of 22 per cent (see page 440) for simple interest, taxes, insurance, and earnings of other capital in the business. The other four lines are also based on the same 22 per cent but their position is modified by the effect of the value of $(1 - M/P)$ (see page 443).

If the chart ⁴ is used to solve the example on page 446, follow the dotted lines to see how easy the calculation may be made. Since the ratio $A/C = 46/0.153 = 300$, note where the line 300 crosses one of the five oblique lines marked

$$\left(1 - \frac{M}{P}\right) = 0.6 \quad \left(1 - \frac{1,000}{2,500} = 0.6\right)$$

Then cross horizontally either to the right or left until the horizontal line meets the oblique line representing the total number used per year ($NM = 300,000$). The line through the intersection point marked with O when carried up to the top scale reads 37,000 which corresponds with the other two methods of calculation.

The chart shown in Figure 1 can be used for calculating the economic purchasing quantity by using the lowest of the five parallel oblique lines where the factor $(1 - M/Q)$ disappears because few if any pieces are used during the part's procurement time. This situation is similar for purchasing because the vendor usually delivers the entire purchased lot at one time. The setup cost for purchasing becomes the cost of issuing a purchase order. (See page 109.)

Analysis of Calculated Example. The total cost of a year's supply (300,000 units) varies upward from both above and below the mini-

⁴ Akon, Inc., of 2245 Acorn Road, St. Paul 8, Minnesota, has these charts in 14½" x 22" size for easy reading. They are reproduced on ledger stock and cost \$1.25 (prepaid) for those who do not care to construct their own. Please state the total inventory charges desired for simple interest, taxes, insurance, and earnings of other capital in the business as a basis for constructing the chart.

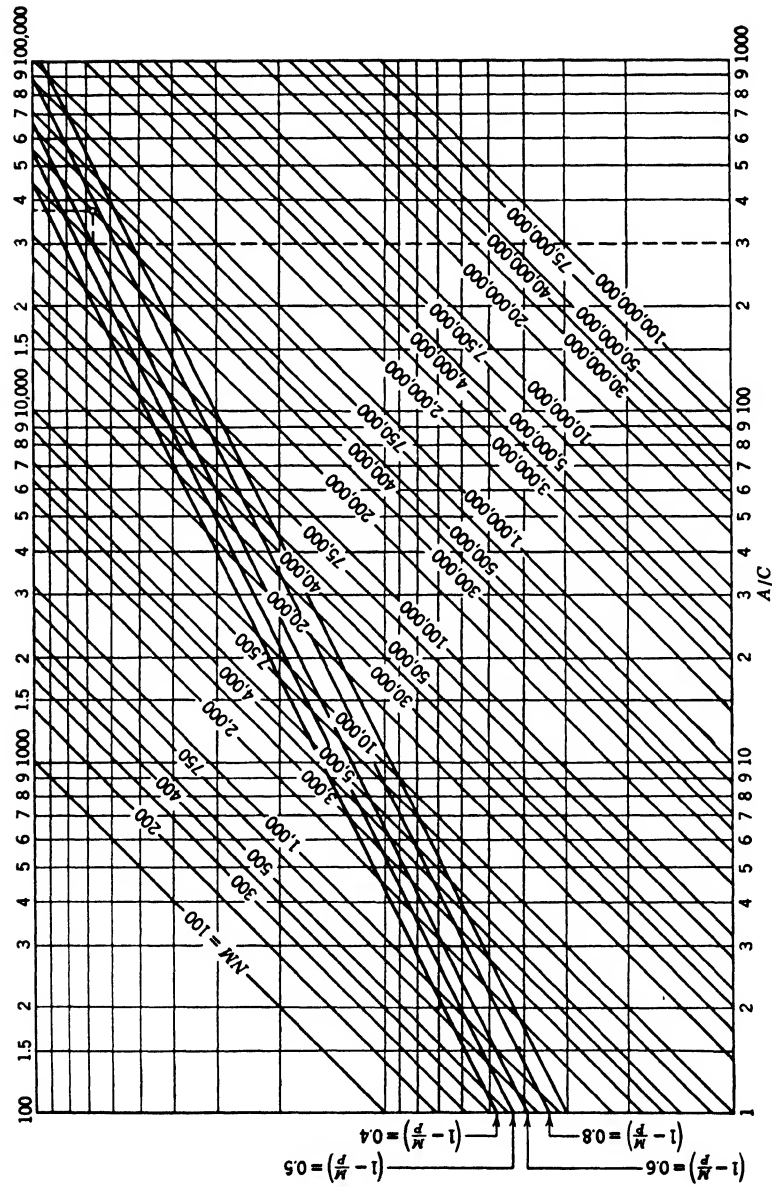


FIGURE 1. Nomographic chart for determining economic lot sizes.

num, but if quantities are smaller than the minimum the errors are apt to be more serious. Figure 2 is a curve drawn by assuming values of Q from 1,250 to 250,000 in equation (1), page 441. Note how the cost of a year's supply increases rapidly if lot sizes of less than 25,000 units are placed in production. On the other hand lots beyond the economic limit of 37,000 units increase the cost of a year's supply at a much slower rate. However, the *capital invested in the additional inventory if the economic lot is exceeded* will be increased proportionally.

Where companies are short of working capital, the economic lot size can be reduced to the point where the total cost of a year's

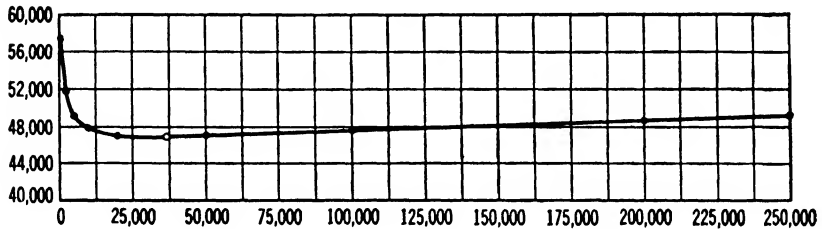


FIGURE 2. Effect of lot size on the cost of one year's supply. The abscissas represent the number of pieces in the lot. The ordinates represent the total cost of one year's supply.

supply is seriously increased. If the production runs too much below the economic ideal, not only is the product cost increased but the shop capacity (see page 306) may be seriously decreased owing to an increase in the number of setups.

If a company is not hampered by a shortage of working capital, it may be desirable to increase finished inventories at certain periods of the year to keep the labor force intact during slack times. Figure 2 illustrates in general and equation (1) on page 441 shows in particular how much the additional inventory, caused by longer than economic runs, will add to the cost of a year's supply. If the company can afford to finance the increased inventory it is well to know also how much the product cost will increase. (See Chapter XVII.)

Procedure for Calculating Lot Size for a Part with More Than One Operation. Usually a part or material requires more than one operation to complete it. Each operation on the part might have a different economic lot size if it were calculated separately because the setup charges for the several operations may be different. If each operation were calculated separately, any differences in the quantities to run on the various operations would be difficult if not impossible to carry out. It is always desirable to complete the part or material run as soon as

possible after the raw material is released. This reduces the process inventory and keeps the plant clear and open for new orders.

The procedure generally used is to add the various items of direct labor, raw material, and overhead charges for all the operations to get the part's value for *C*. Likewise, the various setups and other preparation charges for all the operations are added together to get the value of *A*. In other words, all the operations used on any one part or material are considered as one big operation when economic lot sizes are calculated.

Experience with Economic Lot Sizes. Eli Lilly and Company have been working with economic lot size problems since 1918. During 1917 their production of goods for that year was made in 25,633 batches. By 1928, although the volume of goods had been materially increased, the number of batches had been reduced to 13,453. This downward trend in the number of batches has continued through 1947.

YEAR	NUMBER OF BATCHES
1935	13,058
1936	13,031
1937	13,418
1938	10,948
1939	10,542

Merely counting the number of batches produced per year does not tell the complete story. No lot sizes have been increased to an uneconomic level. The production control department has learned more about applying the formulas, and data are more complete for the preparation and fixed costs. The fixed costs per lot for some items have been found to be very high. In addition, quite recently some of the maximum lot sizes were substantially increased because production procedures were revised.

Because of abnormally high fixed costs per lot for some items, a reduction of 12.5 in the number of lots per year produced a saving of \$1,100 per year in direct cost. Similarly, some further changes in procedures which are being contemplated to remove another eighty-seven lots from the yearly total will save about \$4,000 more per year.

The long experience of Eli Lilly with calculated lot sizes has been very satisfactory and profitable. The company has stated (in 1948) that it continues to profit by the use of economic lot sizes which are mathematically calculated. The losses caused by errors when lot sizes are estimated would be far greater than the cost of accurately determining the correct lot sizes.

During a recent Eli Lilly expansion program the necessary capacity of the new equipment to be purchased was determined by economic

lot size calculations. These calculations provided an accurate specification upon which the machine sizes could be intelligently purchased.

No products are made at Eli Lilly except for stock. Determination of economic lot sizes provided a method of fixing production schedules which processes and stores the many products at the lowest total cost. They have been using these methods with constant improvement for 30 years and intend to continue indefinitely.

QUESTIONS AND PROBLEMS

1. What is the trend of setup costs?
2. Why is the setup per unit low in mass production?
3. What is an economic lot size?
4. Discuss the desirability of keeping manufacturing costs per unit low compared to keeping inventory costs per unit low.
5. Discuss the variables which may affect and possibly should be considered in a general economic lot size calculation.
6. What symptoms would you look for to determine the possibility of uneconomic lot sizes?
7. Discuss the requisites of a real saving in charges for space.
8. When can average space be used in calculating space requirements and what type of industry can use average space requirements?
9. Justify an inventory interest charge.
10. Is it desirable to charge inventory investment an amount equal to what other capital earned in the business? What effect would this have on the economic lot size?
11. Discuss the various costs that should be included in the preparation charges for an economic lot size calculation.
12. The cost of issuing a manufacturing order in a certain jobbing shop is \$4.80. Setup costs on the five operations necessary to produce part 438 are \$8.70, \$3.22, \$10.00, \$28.60, and \$15.80, respectively. The part can be produced at the rate of 450 units per day, but it is used at an average rate of 250 units per day during the season from April through September. Material costs 80 cents per unit, labor 46 cents per unit, and overhead is 175 per cent of the payroll. The unit measures 12 inches by 8 inches by 6 inches and floor space in the finished parts storeroom costs 30 cents per square foot per year. Stockroom ceilings are 8 feet high. The unit weighs 16 pounds. A reserve stock of 30 per cent is necessary. Taxes and insurance on inventory are $2\frac{1}{2}$ per cent per year. Capital earned 12 per cent last year in this company. What is the economic lot size for part 438?
13. What effect would the fact that, on the average, 375 units per month were used from October through March have on the economic lot size of part 438 in Problem 12?
14. Neglect the storage charge in Problem 12. Would this seriously affect the result?

15. Part 46341 for a washing machine requires a storage space of $1\frac{1}{2}$ cubic feet. Storage charges average 7 cents per cubic foot per year. The part is produced as a stamping at the rate of 800 pieces per eight-hour day. Press labor is paid 70 cents per hundred pieces, and the overhead on this press is \$4.25 per hour. However, only an average of 175 machines is produced each day. Thirteen pounds of sheet metal at $5\frac{1}{2}$ cents per pound are used to make the piece, but the finished piece weighs $7\frac{1}{2}$ pounds and scrap is worth \$15 per ton at the plant. Production orders cost \$2.75 each for preparation and distribution. Setup of the compound die on this job takes three hours at 95 cents per hour. A reserve stock of 50 per cent is used on this part. Taxes and insurance are rather high at 5 per cent of the inventory value. Capital has earned 16 per cent in this plant for the last two years. How many pieces should be made in one lot to get the best combination of costs for the company?

16. Suppose a more rapid press were purchased and production were increased to 1,200 pieces per eight-hour day. How would this affect the lot size in Problem 15? Overhead per hour on this faster press is \$5.50 per hour.

17. Neglect the reserve stock and calculate the change this would make in the lot size of Problem 15.

18. Under what conditions should the calculated lot size in Problem 15 be questioned?

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CHAPTER XXI

SCHEDULING AND RELEASING ORDERS

Scheduling has been defined as the process of fitting jobs into a logical time table. The most familiar example of scheduling is the planning of the movement of the various classes and types of trains on a modern railroad. Fast and local freights, several classes of passenger, mail, and express trains, and even inspectors' motor cars and maintenance trains must all be scheduled accurately to avoid accidents and costly train delays. All these trains and smaller units must be run over fixed tracks with turnouts or sidings at proper intervals.

No first-class railroad running more than several trains a day would consider operating without definite train scheduling. But the average jobbing shop is routing its work over paths which also are limited in carrying capacity, and some shops are not scheduling the work through the machines. If the shop operating on a noncontinuous basis does not schedule its work according to some plan, it is doubtful if all portions of the order can come through to the assembly at the proper time. Delays in the delivery of finished parts are disastrous to the prompt completion of an assembly. Parts delivered to the finished stockroom or to the assembly floor long before they are needed tie up unnecessary capital. Moreover, parts on hand too soon may disappear, may be damaged by excessive handling, or may occupy valuable space too long. Jobs or trains which are too early or too late do not keep satisfied customers.

Routing generally precedes the scheduling function, particularly in the detailed operations used to produce the several parts. However, where time is an important factor in a crowded shop, an important job may be scheduled first, and routing through the various machines is arranged to fit the schedule.

Schedules Must Be Flexible. The function of scheduling is a dynamic thing. Manufacturing orders or blocks of work are continually introduced into the busy factory. Regardless of whether the size of the order is determined haphazardly or by means of good economic lot size calculations, the block of work must be fitted into the shop schedule. Existing schedules often must be changed to make way for

more urgent jobs. Sales and production capacity are thus coordinated by careful scheduling.

Methods of Scheduling. When proposed blocks of work are released to the factory, the production control department prepares a plan for action. For new work this plan includes the analysis of the product to determine manufacturing operations and their sequence as discussed in Chapter IX. It often includes the estimation of production rates and capacities as discussed in Chapter XII.

After these preliminary plans are completed, the correct amount of productive capacity for the new order is determined and dovetailed into reservations which have been made previously. A master schedule is compiled to show, first, the total time available for the entire job if it must be finished by a certain time and, second, how the various portions of the job are to be scheduled. Such preliminary schedules are usually exploratory in character to get the time requirements of the various functions and operations placed in their proper sequences. Generally it is necessary to have certain things such as design, material purchasing and receiving, special jigs and fixtures, and operation sheets ready before actual manufacturing can start. If the normal times for these functions are added together and if their total is more than the desired schedule can absorb, it is often necessary to make adjustments to speed up the end result. Such adjustments sometimes require the dovetailing of functions. For example, it is not always necessary to wait for all the detail drawings before tools and operation sheets are prepared for the drawings which have been released. As fast as material needs are apparent, the purchasing department can start work on acquiring the materials.

Often a preliminary survey will reveal that certain parts or materials will require a longer time to process and/or purchase the material. Such parts should be designed or specified first so that they may be released early to gain valuable time in manufacture. A preliminary analysis of a master schedule will often show the way to decrease the over-all time required from sales order to shipping or delivery to customer.

Figure 1 shows a theoretical diagram for arranging a schedule. The various portions of the entire job are shown as they progress from left to right. The space between the vertical lines does not necessarily indicate the relative times for the various functions, but the procurement and operation times are arranged to show that some operational and procurement times are longer than others. Even though some may be longer the finishing operations on each item are scheduled to be completed for the subassemblies at the same time.

Item *A* has both a long procurement and operational time. This means that item *A* must be ordered from the vendor to be delivered in advance of the other items. Item *F* also has a long procurement time but time for fabrication in the shop is quite short, so it does not need to be brought into the plant as early as some of the other items. Attention to such actual need for materials to fit into a master schedule will increase the inventory turnover and reduce the need for working capital.

Figure 3 of Chapter XVIII shows a master schedule which was used to get a new machine into production. This firm had previously

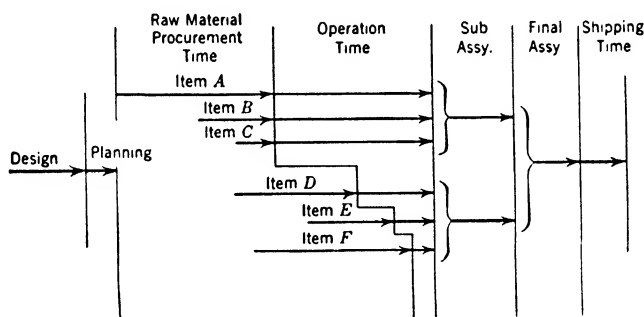


FIGURE 1. Diagrammatic plan for arranging a schedule.

made promises on delivery of other new products but these promises were based on wishful thinking. On this particular machine for which the master schedule was prepared, the performance was quite close to the original schedule. Note that considerable dovetailing was done on all the functions except experimental ones. In fact the size and type of motors were determined early in the experimental work so that the purchasing department could get started on the necessary long lead time. As soon as any other of the hard-to-get items were determined in the experimental machine, they were released for purchasing. Parts were coming in from subcontractors and the company's own machine shop before all the other parts had been drawn. This of course imposed certain risks but generally subassemblies were released which were interrelated so that tolerances and fits could be checked.

It was possible to check the performance of each group to determine if its portion of the total job was ahead or behind the scheduled performance. Figure 4 of Chapter XVIII shows a detailed schedule of drawings, master parts number record cards, and part lists checked for performance against the scheduled performance. If any portion

can be made for a series of events. This chart¹ was prepared and used by the Morton C. Tuttle Company to schedule and to show the relation of performance to schedule for an office building. Thirty important events were arranged, numbered, described, and scheduled in this chart. The beginning of the excavation to the building's acceptance by the owner was scheduled over a thirty-three-week period. The heavy horizontal lines indicate the scheduled time for each event. The broken lines indicate whether each step was on schedule, behind, or ahead of schedule. The X in the third column from the left indicates an operation that is behind schedule. The next column from the left shows the percentage of work completed on each item on the date indicated by the V. When this line is drawn completely across the column that item is finished and needs no further attention. The schedule is posted each week and the newest edition is sent to all concerned to show clearly progress and any delays which may exist. Thus, management can watch delays as they occur; it can predict the effect of the delay; and it can also take steps to eliminate delays before they become serious. Such scheduling and final checks on the results are invaluable in predicting performance on future jobs.

Master Schedule for Lot Production Manufacturing. Another type of master schedule is used to indicate the relative importance of manufacturing orders. Plants manufacturing large quantities of products of the same general character need a master schedule to guide their operations. Such shops often use motion and time studies to standardize their operations thoroughly wherever possible. Thus shop productive rates are well known and can be predicted quite closely.

Sales budgets or actual customer's orders may show what is needed for several months in advance. The orders coming from the various sources usually include a number of similar products. Moreover, if the plant has instituted any plan of standardization of parts in the various products and models, some further grouping of like parts in a given period can be used to build up a sufficient number of pieces for an economic lot size.

The planning department gathers together all the orders for each part and groups them for further study. (See page 386.) Often a job shop will receive a large order for parts or assemblies which are to be delivered in smaller lots at stated periods. The number of pieces to be shipped in each lot is sometimes determined by an economical

¹ *Principles of Industrial Organization*, D. S. Kimball, Sr., and D. S. Kimball Jr., McGraw-Hill Book Co., 1939, p. 203.

freight or truck shipment. Both the vendor and vendee profit if the product can be shipped as it is produced and used as it arrives.

Master schedules for this type of production are made by grouping all the products of one type which are to be made during the next period. For manufacturing purposes the master schedule of assemblies is broken down into a parts schedule which shows the *quantity of each part* to be made during the period. If the manufacturing time for the required number of pieces of a certain part will take more than the normal machine time available during the period, these pieces may be subcontracted, the shop may work overtime, another shift may be

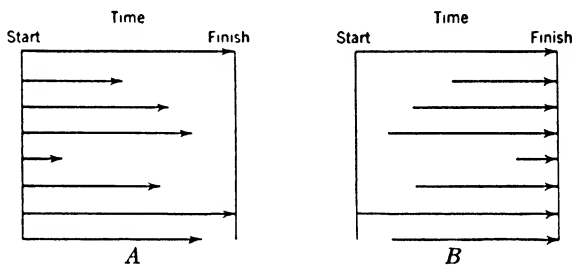


FIGURE 3. Two methods of scheduling. Method A is wrong. Method B is correct.

added, or additional capacity may be required. Management must decide which alternative is best under the existing circumstances. The important thing is to know in advance where the bottlenecks are going to develop.

Scheduling Parts with Different Process Times. In plants where some parts for a machine require a considerably longer time to complete than others, a method of scheduling each operation so that all parts will be completed at approximately the same time is considered good practice. By delaying the delivery of raw material to the plant and the completion of a part until it is actually needed for the assembly schedule, savings are made which may be important. Parts need not be stored finished, waiting for assembly. Material need not be purchased until the operations are scheduled to begin. Working capital is more effectively used if the schedules are planned in this manner. Figure 3 illustrates graphically the difference between two methods of scheduling operations. Method A requires larger capital investments, larger storerooms, and greater chance for possible waste than does method B.

The above type of scheduling is particularly useful if only one or several large projects are to be produced, for there usually are not enough pieces of any one part to warrant economic lot size calcula-

tions. Moreover, even if there were a number of pieces to be made, all of them would be necessary for the actual order on hand.

Use of Schedule Sheet as an Aid to Scheduling. To set up a detailed schedule of work flowing through the plant, a schedule sheet is a valuable aid. Figure 4 shows the time for performing the operations on part 58118 as outlined in Figure 3 of Chapter XI. This part is to be made in an economic lot size of 375 units.

Determining Schedule Times. The inspection operation is done by the random sampling method (see Chapter XIII) which increases the inspection speed to a rate of 1,125 pieces per hour. Thus the inspection time for the lot is twenty minutes, or one-third of an hour. In this particular shop it has been found that an average of one-half hour is necessary for moving material from one operation to the next. Thus, if it is assumed that the entire 375 pieces are finished before they are moved to the next operation, the trucking time would appear between each operation. The setup time, when it is needed, is added to the operation time. The standard time is calculated from the operation sheet. Operation 1 has a standard production rate of fifty pieces per hour or $375/50 = 7.5$ hours for the lot of 375 pieces. Setup time is included in the total time for the operation, which together with the 10 per cent safety factor in this case is the scheduled time. $(7.5 + 0.75) + 0.10(7.5 + 0.75) = 9.1$ hours (to the nearest tenth of an hour). Standard trucking time plus the 10 per cent is allowed between each operation. The time for each operation is calculated from the operation sheet in the same way until all the scheduled hours are listed on the schedule sheet. The total of these hours for 375 pieces of part 58118 is 20.9 hours as shown in Figure 4.

The average transportation time between operations would vary widely in different departments and plants. In some situations where the plant is large or the department is crowded, it may take an average of several hours for transportation. This average should be set by a study of the transportation department under the conditions which exist.

Percentage Allowance over Standard Time. The percentage allowance over the standard operation and average transportation time is also fitted to the situation at hand. Some shops cannot work on a schedule close to the standard time because of lack of organization, variable materials, poor equipment, or other disturbing factors. On the other hand, the shop which is skillfully controlled can schedule quite closely to the standard time and not much allowance is necessary. If work is always behind schedule in a shop the safety factor is not large enough or the shop operations should be better controlled.

SCHEDULE SHEET

Part Name Rear Stud Part Number 58118 Mfg. Order Number 10231

Quantity Ordered 375 to be continuously processed in 1 batches Allow 10 % over operation time for scheduled time

Starting Date December 10 Due in finished stock December 13 Scheduler C. Howe

Operation Number	Scheduled Time in Nearest Tenths of Hours for Each Operation	Due at Machine in Continental Time	Operation Finished in Continental Time	Remarks
#1 including setup truck	9.1 0.6	Dec. 10 -- 10.1	Dec. 11 -- 11.1	
#2 including setup truck	3.6 0.6	Dec. 11 -- 11.8	Dec. 11 -- 16.5	
#3 including setup truck	4.6 0.6	Dec. 12 -- 8	Dec. 12 -- 13.8	
#4 no setup truck	0.8 0.6	Dec. 12 -- 14.2	Dec. 12 -- 15.3	Behind schedule
#5 no setup truck	0.4	Dec. 12 -- 15.6	Dec. 12 -- 16.1	
	$\frac{20.9}{8} = 2.6$ days			

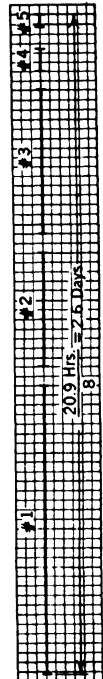


FIGURE 4

Effect of Excessive Allowance for Transportation and Safety Factor. Incidentally, when the safety factor and the time for transportation are increased, the shop becomes more crowded and the investment in process inventory becomes greater.

Writing the Schedule Sheet. Figure 4 is filled out to show the scheduled time for "Due at Machine" to the nearest tenth of an hour. These hours are shown in continental time which is generally considered easier to calculate. In this time system the hours are numbered from 1 at 1 A.M. to 24 at midnight. Thus 8 in the morning is the eighth hour and 5 in the afternoon becomes the seventeenth hour.

Schedules may be projected forward from the time the material is due at the first machine or, more generally, they are projected backward from the time the part is needed for future operations. The schedule for part 58118 in Figure 4 is projected backwards from December 12—16.0. In this form each operation is finished on all the parts in the lot before the next operation is started. In other words, the lot of 375 pieces is continuously processed and transported to the next operation in one batch.

If December 12—16.0 is the scheduled date for operation 5 to be finished, this operation should be ready to start 0.4 hour earlier or at December 12—15.6. The scheduled time for operation 4 is 15.6—(0.6 trucking time + 0.8 time for operation 3) = 14.2. Likewise, operation 3 is 14.2 — (0.6 trucking time + 4.6 time for operation 3) = 8.0. (The twelfth hour is the lunch hour.) Since the eighth hour is the starting time for the plant, this consumes all the hours available on December 12; operations 2 and 1 are projected backwards in the same way until it is known that operation 1 is scheduled to start on December 10 at the 10.1 hour.

As the part is processed in the shop, the finishing time for each operation is written or stamped in by a job clock. Operation 4 was 0.3 hour behind schedule but quick transportation saved enough time to finish the last operation only 0.1 hour behind schedule.

Often it is not necessary to show the scheduled time for each operation where the over-all time is short. Only the scheduled time for "Due at Machine" for operation 1 and the "Due in finished stock" would be needed. The total scheduled time of 20.9 hours or 2.6 days would determine either the "Due at Machine" or "Due in finished stock" dates, depending upon the method used for determining the date.

Dovetailed Operational Scheduling. In some plants where not enough time is available for a large lot when each operation is completed before the next operation is started, or where process inventories are expensive, the parts from one operation are started in the next oper-

ation just as soon as possible. It is unwise to start the next operation if it is faster than the preceding one until enough parts are ahead so that the faster operation cannot catch the slower preceding one before the lot is finished. These facts are determined from the production rates on the operation sheets, and the schedule is arranged with a safety factor large enough to avoid trouble.

Figure 5 illustrates how time may be saved in processing the same manufacturing order 10231 by starting succeeding operations before the preceding operations are finished. The scheduled times for the operations and transportation are the same as those used in Figure 4. The lot of 375 pieces is transported, where necessary, in three batches of 125 pieces each. Since operation 5 is so short no attempt was made to start it before operation 4 was finished. Operation 4 is faster than 3, so the last 125 pieces must leave operation 3 in time to allow 0.6 hour for delivery to operation 4 and yet leave time for the last third of operation 4. The graph section of Figure 5 is used to chart this schedule. It is generally easier to chart this kind of a schedule because one can clearly see if it is correct. However it can be calculated and the "Due at Machine" dates placed in the schedule sheet. The "Due at Machine" dates can be measured off the graph or calculated and placed on the schedule sheet.

Operation 2 is faster than 3, so it is necessary to have time for the first 125 pieces plus time for transportation to operation 3 before operation 3 can be started. This projects operation 2 to the left $0.6 + (3.6/3) = 1.8$ hours beyond the starting time for operation 3.

Operation 1 is considerably slower than 2 so that the same method is used as was used to place operation 3 on the graph. The finishing operation 1 is placed 0.6 hour (for transportation) to the left of the last 125 pieces of operation 2.

Drawing the Schedule Graph. A triangular wooden rule graduated in tenths, twentieths, thirtieths, fortieths, fiftieths, and sixtieths of an inch is ideal for laying out these charts. Starting and quitting time, noon hours, and shift hours can be marked on such a scale to chart the schedule quickly.

Time Saved by Dovetailed Scheduling. For part 58118 manufactured in lots of 375 units the difference in time between the two types of schedules is $20.9 - 15.5 = 5.4$ hours or about 27 per cent. This saving in time means faster over-all production and less process inventory investment, but the savings should be checked against the increased transportation cost. Three times as many trips are made to deliver the parts in manufacturing order 10231 as were used in the first method of scheduling.

SCHEDULE SHEET

(Example of time saved by dovetailed scheduling)

Part Name Rear Stud Part Number 58118 Mfg. Order Number 10231
 Quantity Ordered 375 to be continuously processed in 3 batches Allow 10 % over operation time for scheduled time
 Starting Date January 6 Due in finished stock January 9 Scheduler G. Young

Operation Number	Scheduled Time in Nearest Tenths of Hours for Each Operation	Due at Machine in Continental Time	Operation Finished in Continental Time	Remarks
#1 including setup truck	9.1 0.6	Jan. 6-- 16.5	Jan. 7--15.1	
#2 including setup truck	3.6 0.6	Jan. 7-- 15.8	Jan. 7--17.0	
#3 including setup truck	4.6 0.6	Jan. 8-- 8.6	Jan. 8--13.7	
#4 no setup truck	0.8 0.6	Jan. 8-- 14.2	Jan. 8--15.2	Behind schedule
#5 no setup	0.4	Jan. 8-- 15.6	Jan. 8--16.10	

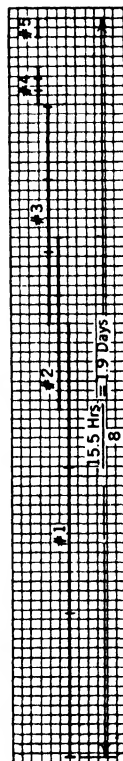


FIGURE 5

The operation sheet shown in Figure 9 of Chapter XI illustrates a simple method of detailed scheduling for part number 7162-1. The manufacturing order 5606 which calls for the economic lot size of 300 pieces was released on 1/3, a full two weeks ahead of the scheduled starting date for operation 10.

From the standard hours per 100 and the setup time it is easy to calculate the time for each operation. Thus $(300 \times 0.5) + 0.1 = 1.6$ hours for operation 10, and $(300 \times 0.8) + 0.2 = 2.6$ hours for operation 40. The scheduler "S. B." calculates the hours scheduled, posts them on the machine load (see Chapter XXII) for each machine involved, and determines a starting date for each operation. These starting dates have enough latitude to allow the dispatcher some flexibility in releasing the various jobs to the specific machines.

Since this manufacturing order was released for duplicating the various forms (see Chapter XXIII) on the date 1/3, the dispatcher would have his copies of the manufacturing order about one week ahead of the scheduled starting date. With this flexibility the dispatcher can manipulate his assignments of operations to the shop to fit the current conditions. The actual dates the operations were released to the shop are shown by the last two columns on the right side. The dispatcher records the date and signs his initials when the machine operator is assigned an operation. As long as the dispatcher gets the part finished by the date due (1/28) no delay will occur at the point of assembly even if the starting dates for all operations were not actually followed in all cases.

The Gantt chart or its many modifications are often used to present a schedule graphically. Such presentation places the problem out in the open where all interested persons can observe its status as compared to the ideal. Again it should be stated that being ahead of schedule on part of a major project is not so good as it sounds. It may involve the expenditure of working capital before it is necessary, use valuable storing space, and cause damage by carelessness during the storage period. A graphic chart which shows *all* parts, subassemblies, and sections of the work moving along in a balanced condition either on or slightly ahead of schedule is a real satisfaction to the production organization.

The Producon version of the Gantt chart provides a method of presenting information for many types of commercial and industrial problems. Figure 6 illustrates and explains the various components of the board as it is set up to schedule and shows the progress of a number of orders.

Following the receipt of an order from a customer, the order is scheduled through the various necessary steps to complete it. The order is entered on a record card, Figure 7, and placed in a card pocket in the record panel (see Figure 6). In line with each record card pocket, a double row of 200 peg holes extends horizontally across the

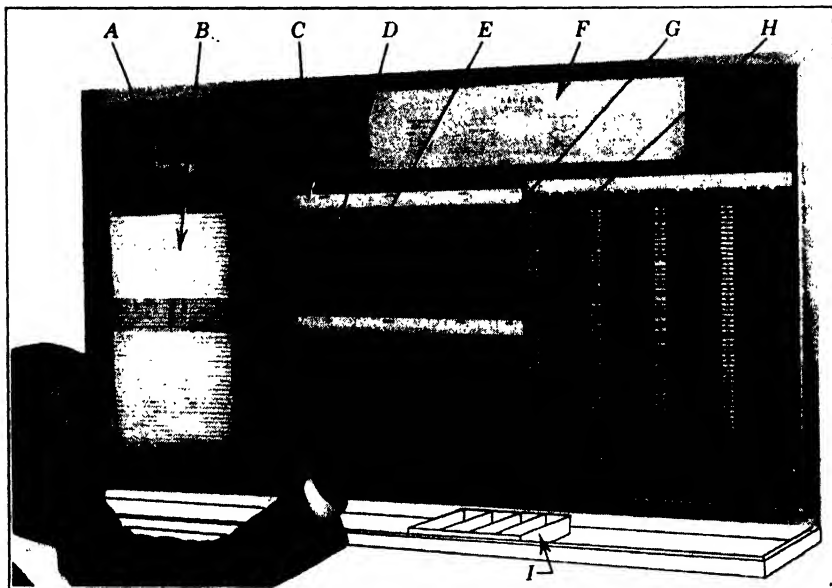


FIGURE 6. Graphic chart to show progress of orders.

- A*, record panel. Container for card pockets. Removable for work at desk.
- B*, pockets. For visible index and record cards. Come in various sizes.
- C*, heading strip. Replaceable card strip calibrated in "time" and "quantity" values.
- D*, progress tape. A flow line to indicate progress against any predetermined schedule.
- E*, today line. Moves across the board daily, indicating today's date.
- F*, legend cards. Showing color and shape of signal pegs and what they represent.
- G*, signal pegs. Inserted in peg holes to indicate "quantity" and "time" values.
- H*, peg hole section. Entire area of board.
- I*, peg box. Divided into compartments for the various colored pegs.

board. The left-hand side of the board is divided into as many sections as there are major operations or departments through which an order may be scheduled. Vertical cords are provided for this purpose, separated by five to ten peg holes for each operation or department involved (see Figure 8).

If desired, the date the order was received can be shown on the chart by inserting a small round signal peg under the proper date line, as shown in Figure 9. The progress tape peg, which is a cord attached to a round peg numbered to correspond with the numbered

record card pocket, is drawn out to show the scheduled completion date of the current operation. As the work on the current operation progresses, the progress tape remains in its original scheduled position, but when the current operation is completed the progress tape peg is moved to show the scheduled completion date of the next operation.

A vertical today line cord is advanced to show the current day or period. As the today line approaches the progress tape peg showing the scheduled completion date of the current operation, a check should be made to ascertain whether the operation is on schedule. If not on schedule at this time, action is necessary to correct the deficiency. Any progress tape peg falling to the left of the today line shows a behind-schedule condition, requiring an active, aggressive program to bring the part or project up to schedule again. The number of peg holes between the today line and the progress tape peg indicates the *length of time* behind schedule. If the space increases each day the seriousness of the problem is emphasized.

Additional information can be posted on the chart by using a round-shouldered peg to show the present location of an order by date line and a square-shouldered plug to show the scheduled finished date of the order.

Scheduling for Mass Production. The master schedule for the continuous plant is quite simple. It consists mainly of a statement of the number of units of the different products which are to be made during the period. The master schedule is broken down into the actual parts needed. These parts are run through the line production machinery which generally automatically routes and schedules them for delivery at the proper point for assembly at the proper time by means of conveyers. The routing and scheduling for such plants are largely done when the plant is designed for the product.

The modern automobile final line assembly is to some degree an exception to such automatic scheduling. A dealer is quite often allowed to specify color, type of body, and upholstery for the cars he buys. In the schedule for automobiles, the correct body and other units move along the conveyers so that all the units ordered will be delivered at the proper place to enable the mechanic to place them without thinking and yet fulfill the car dealer's requests.

Schedule charts for final automobile and truck assembly lines list the various combinations of chassis frames, axles, body types, colors, upholsteries, and other special requirements on duplicate sheets for each station in charge of parts which may vary. Since any conveyer which carries a major part is fixed in length from the loading point

to the final assembly line, it is easy to place the several required parts in the proper sequence by having the several conveyer loading stations follow the printed schedule. Thus the parts flow to the final assembly line to produce the special requirements specified by the dealer.

Benefits of Scheduling. Most plants have enough information in their files to set up schedules for new work. Often, however, it is necessary to gather and arrange the data before they can be released in usable form. An estimated performance used as a basis for scheduling is far better than no scheduling at all. Even poor estimates can be improved by checking them against the actual performances, making the proper adjustments, and recording the revised estimate for future scheduling of the unit.

The discipline which scheduled performances can develop in a plant's organization is invaluable for the future of a company. If each supervisor is held responsible for his portion of the schedule, he knows *in advance* when he is falling behind. The supervisor's plan for action to get on schedule again is often a measure of his worth as a supervisor. The action may vary from the judicious use of overtime for certain bottlenecks to elaborate plans for requesting additional capacity, men, money, or materials needed for the job. Sometimes the discipline extends to the sales department and even to the top officers who are often too optimistic concerning delivery dates when schedules are crowded.

Production control can predict delivery dates rather accurately if consulted first. However, if a difficult order has been accepted with the delivery promised, a master schedule should be set up immediately to plan each important event in advance. In turn, the various steps including drawings, purchasing, machining, assembling, and testing should be scheduled in detail through each department. Thus everyone concerned will know his portion of the whole, and by a systematic check at stated intervals the progress of each operation can be checked.

QUESTIONS AND PROBLEMS

1. Does scheduling precede or follow routing?
2. When manufacturing orders are repeated, how much planning must be done?
3. How does scheduling for a large machine or project differ from the planning for an economic lot size?
4. How can good scheduling conserve capital?
5. Prepare a master schedule for the preparation of a major report on the performance of a large hydraulic press or a 50,000-kva turbine.

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CHAPTER XXII

MACHINE LOADS

Machine load may be defined as the number of hours of work assigned to each machine or group of similar machines beyond the current date. It is a figure that may change daily and the records, to be of maximum value, must reflect the changes.

Each new job assigned to a machine increases the future load factor, and each finished job reduces the load already assigned. Some machines, such as those usually found in a machine shop, generally have their loads expressed in hours. However, where the machines are used for the same product, such as packages of cigarettes, barrels of flour, or yards of knitted goods, the loads can be expressed in terms of the product. For example, the capacity of a flour mill is expressed in barrels per day, and the mill's load for future orders or a production program can be expressed the same way.

Where the machines are used to produce products that may vary in the facilities used, the load factor is estimated from a route sheet or accurately determined from an operation sheet which may have all the operations time-studied. In addition machine loads have to include the setup or preparation time for each machine when a job is changed. In short runs this setup time may be an undue proportion of the productive time.

Objectives of Machine Loading. Machine loads are of particular value to the sales and production executives of an industry. They provide an accurate method of showing the back log of work in the plant. Moreover, the unbalanced conditions in different portions of the plant can be clearly shown by comparisons of machine loads. It is well to remember that most plants are not able to obtain 100 per cent use of each machine's time. Power or machine breakdown, replacement of dull or broken tools, material shortages, lack of manpower, lack of work, and excessive setup time reduce the continuous use of any machine. In some metal-working lot production shops, an 80 per cent use of a machine is considered good. However, flour mills have a use factor generally over 95 per cent. Specialized bakeries, such as for bread, also have high machine use factors. Each plant

should strive to increase the use of capacity factor to the highest economical level. Striving for use factors beyond the economic limits may mean having too many maintenance men, too many setup mechanics, and probably too many control clerks and dispatchers who have too much idle time. The law of diminishing returns begins to operate if an attempt is made to increase the efficiency of any machine or process beyond its economic limit. (See Chapter XIV.) By comparison with other plants in the same type of manufacture, a particular plant can know if it is utilizing its machinery as well as the average in the industry. Such an average may be below the economic limit, and the best plants in an industry can usually maintain a slightly higher percentage of use without excessive cost for the amount gained.

Some plants keep a record of machine down time either by individual machine, by groups of similar machines, or by departments, such a record should show the number of hours of down time and the respective causes. If such a record is analyzed it may reveal several pertinent facts. Some machines may need too much maintenance and should either be given a thorough overhauling or be replaced. Some operators may not be dependable and should be shifted or discharged. Material shortages or power and tool difficulties usually can be corrected if carefully studied. When lack of work is the cause of idleness the sales department should be notified as soon as possible so that more capacity may be sold.

Effect of Overload. A single-shift forty-hour week has only forty hours capacity available from each machine unless overtime is used. The assignment of any new job to a machine, group of machines, or process center consumes some of the capacity available for future work. If more work is assigned than there are hours in the normal period, several alternate courses of action are possible. Some of the load can be shifted to other machines, not completely loaded, which can do the work. For example, shifting the finishing of flat surfaces from milling machines to lathes or to planers and shapers often is feasible. Alternate methods may cost more but they may help a production program over a critical period. Overtime can be used in emergencies for occasional overloads, but overtime rates are from 50 to 100 per cent higher in cost than normal time. Moreover, the fact that long periods of overtime reduce the output of work from all hours worked make overtime as a regular policy rather expensive. Sometimes a search for better methods including more productive auxiliary tools, improved material handling, elimination of wasted or lost time, and even better scheduling may increase the production on a group

of machines and thus increase their ability to absorb more load. Subcontracting the bottlenecks and excess loads is quite commonly used to relieve temporary or seasonal peak loads. Finally additional capacity should be installed to absorb a persistent overload of sufficient intensity to use the output from additional machinery. (See Chapters XIV and XV for the danger of overcapacity.) In certain types of industry a second shift may help to solve consistent overloads at less cost than the purchase of additional equipment.

Effect of Underload. The underloading of a machine may be caused by any one of several factors. Some are serious; others are temporary and can be easily corrected.

One of the most serious mistakes is overoptimism without making an economic study when a machine is purchased. (See Chapter XV, page 329.) Expensive machines which produce more than can be used in the predictable future are often bad capital risks. Such overcapacity is often difficult to keep loaded because a serious unbalance in other portions of the plants' capacity may develop.

If a machine or group of machines have been loaded in the past but are later underloaded, the cause should be determined and corrective measures applied if possible. Sometimes products change or a new method is developed which makes the old machines obsolete or unnecessary. Management should decide either to sell them, to hold them in reserve, to develop new products, or to get some subcontracting work for them. Sometimes the underload can be decreased or eliminated by notifying the sales department in advance to sell more of either product which uses the machines or actually sell machine time for subcontracting purposes.

Custom shops often have chronic underloading of certain machines which still are necessary for a well-rounded custom shop. Some plants reduce such underloading by developing a line of standard or stock products which can be made during periods of serious underloading.

By more emphasis on selling where needed, possible discounts during slack periods (see Chapter XVII), insertion of standard or stock products to supplement the period of low loading, and skillful scheduling with records of machine loads, the underloading of certain sections of plant capacity can be considerably corrected.

Objectives of a Machine Loading Procedure. Machine loading procedures should be organized to keep the plant's machines working at the economic capacity, to assign the best possible machine for the operations at hand, and to assign and schedule the entire group of machines necessary for the complete job so that the total process time in the shop is as short as possible. For job shops working on single

jobs seldom if ever repeated, the route sheet, in combination with the daily scheduling, manipulates the available machinery loads to do the best job. Job lot production and mass-production shops usually have to be much more critical of costs, and consequently their operation sheets (see Chapter XI) are based on extensive study in the beginning. Carefully considered adjustments from time to time may be found desirable from experience. Such operation sheets usually list the best machines and the hours to be used for each operation, and machine loading consists of using the operation sheets as the source of this fundamental data to use as a multiplier. The amount of the product is multiplied by the operation time to get the hours of machine load required to produce the desired quantity. Thus two aspects of machine loading (best machine and hours required) may be served from the same fundamental data on the operation sheets.

The gross load for each machine group used in the processing of a proposed product can be calculated to determine if the additional load can be absorbed during the proposed schedule. If an impossible or even critical load is accumulated in this manner, it is known far enough in advance to avoid bottlenecks. The proposed schedule may be spread over a longer time, or steps previously discussed may be instigated to allow the proposed or adjusted load to be acceptable. If such over-all gross load information is carefully compiled, the assignment of the detailed machine loads may be done on a comparatively short-term basis with much greater assurance that the various totals can be completed on schedule.

Effect of a Fixed Operational Sequence on the Detailed Machine Load.

The detail posting for the various loads can use the same fundamental operation sheet data as discussed above. However, if the posting is done too far in advance, the various changes in schedule, which occur even in the best controlled shops, also make it necessary to revise the detailed machine loading. If the operational sequence is fixed by necessity, as, for example, in the manufacturing of most organic dyes, then machines must be made available for the next operation before the job can proceed. This tight procedure sometimes lengthens the production cycle for a given product because the required machine for the next operation is not always available when the previous operation is finished. However, if the product cannot be held very long between fixed operations for schedule or technical reasons, it usually is necessary to schedule the next required machine so that it will be free in time to be set up or prepared for the required sequence of operations. Since it is not always possible to have the necessary process center or machine ready just when it is needed, the machine

may be held idle after the close of its last assigned operation until the operation which must be in sequence is ready to use the waiting machine. This of course decreases capacity, upsets schedules still more if they are tight, and causes some adjustments to be made in the control procedures.

Effect of a Flexible Operational Sequence. When an operation sheet is written it is necessary to include all the various operations needed to complete the part or product. Sometimes the sequence of operations is fixed for technical reasons and cannot be changed. Often, however, it is possible and sometimes desirable to change the sequence of certain operations to adjust scheduled machine loads to current conditions. Usually certain operational sequences must be followed whereas others are optional. The choice of shifting the sequence of the optional operations must remain under the control of the dispatchers if they are used or the foremen. In either case the shift should be recorded by the *original operation number* on the various production control and cost records so that these records may be accurate.

When the operational sequence is flexible, it is possible to take advantage of gaps in the schedule as they occur and place an optional sequence operation in the gap. Often if some operations cannot be moved out of sequence, the gap in the machine load cannot be filled.

CONTROL PROCEDURES FOR MACHINE LOADING

Scheduling requires an accurate record of the available machine and process center capacity. Such a record includes a procedure for recording the hours or days each machine or group of similar machines are to be occupied by the jobs scheduled ahead. The method of recording machine or process center loads depends somewhat on the methods of operating the shop.

Machine Load Record for Continuous Plants. If the product is made by a continuous process, such as meat packing, flour milling, automobiles and other mass-production metal products, the machines are selected and arranged in groups to provide a balanced load for the products manufactured. If such plants run at all the various portions of the plant are balanced because they were designed that way. If the final product is changed in a continuous industry such as automobiles, the old machines are rearranged, new ones are purchased, or old ones may be discarded, but the changes are studied in the light of the new requirements and the machine load is again brought into balance as nearly as possible. If an additional product is made in

an analytical industry, such as packaged wheat germ in a flour mill, the additional operations are studied to determine the amount of new machinery required to handle the expected volume. The machinery is arranged in balanced load groups in a new department, and the new section becomes another balanced production group tied in with the rest of the plant.

The machine loading for continuous- or mass-production plants seldom requires detailed daily posting of the scheduled load on each machine. The load is recorded for the plant as a whole, usually in terms of product such as barrels of flour or cement, dozens of pairs of nylon hose, or number of automobiles or typewriters.

Machine Load Record for Repetitive Job Lot Shops. A large number of plants are manufacturing their products by processing a number of different parts or materials over the same machinery. If this is done as a regular repeated procedure an operation sheet for each part or material, subassembly, or intermediate is prepared as a record and guide each time a rerun is made. (See Chapter XI.) The size of the lot for each run may vary considerably because of seasonal changes, or it may vary simply because the inventory or lot size is not well controlled. Under certain conditions where sales forecasts and future production programs are regularly used (see Chapter XVII), an economic lot size can be determined which will tend to be fairly constant unless conditions change radically. If the lot sizes for each part can be consistent, the calculations for the machine loading record is recorded the first time and duplicated for future runs.

The operation sheets usually have the standard time per 100 units and the setup time listed for each operation required. The load by part number, operation, and/or manufacturing order number are recorded against each machine or process center required. This may be done on a ledger form of control or graphically by posting the block of work in a time sequence. Posting by either method is often done on a card or sheet assigned to each machine in the plant. If the advance posting is recorded as a changing total number of hours required during the next period as jobs are added and finished, the detailed daily loads are hidden. But if daily loads are desirable, it will be necessary to assign the time required by each lot to a definite day or group of days.

Machine Load Record for Nonrepetitive Job Shops. The machine load record for the nonrepetitive job is a single procedure. The data for the job are usually written on a simple route sheet, and the times for the various operations are usually estimated. Thus the funda-

mental data are not usually so accurate as in the other types of manufacturing previously discussed. A more liberal allowance is often required for each job so that schedules can be met without constant adjustment if the time consumed is more or less than the estimate. If a small bank of work is scheduled ahead of each machine, the most urgent job in the bank will be known and ready to run if the previous job is finished ahead of schedule. The daily tabular or graphic record

Machine Load Card for Machine or Process Center Number <u>62</u>							
For Week Ending <u>5/26</u> Hours to Be Worked <u>32</u>				For Week Ending <u>6/7</u> Hours to Be Worked <u>40</u>			
Mfg. Order Number	Part Number	Hours for This Order	Load Hours Left in Week	Mfg. Order Number	Part Number	Hours for This Order	Load Hours Left in Week
8092	21	3	29	9183	104	1	39
9183	104	30	0	9341	89	15	24
				9379	551	21	21
				9398	109	11	10 13
				9421	211	18	0
				5	8	hours	carried over

FIGURE 1. Tabular method of posting machine load.

is usually best for the nonrepetitive job shop. The loads are assigned by part number, description, or any other identification that will help to specify later what the assigned load is for. Such assignments are made to the best available machine until its capacity has been absorbed. Then either the next best available machine is assigned, or the job is postponed until a proper machine does become available.

Tabular Method of Controlling Machine Load. Figure 1 illustrates a simple card which may be used to post the machine or process center load for each manufacturing order scheduled during the next two weeks. These cards can be filed according to machine numbers or in groups under machine families. Manufacturing order numbers are posted to each machine or process center according to the urgency of the order. For easier identification the part number may be posted also. The number of hours required for each manufacturing order is

posted and subtracted from the load hours left in week from the previous posting. The final figure in the load hours left in week shows the capacity still available for the week. The number of hours to be worked will vary from week to week largely because of holidays or other factors which may increase or decrease the hours worked. In Figure 1 the first week on the card contains Decoration Day, which reduces the work week to thirty-two hours. This means that only thirty-two hours can be scheduled unless overtime or an additional shift is introduced to increase the hours which can be worked in the week.

When the next manufacturing order requires more time than the last load hours left in week shows available, the difference is immediately posted to the first succeeding week which may have room for it, whether it is on the same or the next card.

If the postings are made on the left-hand side of the spaces on the card, changes can be easily made simply by drawing a line through the obsolete figures and writing in the revised figures. When manufacturing order number 9379 was canceled the revision was carried forward until the number of hours carried over to the next week was reduced to five.

Gantt Load Charts. The Gantt¹ load chart is a useful device to show how much work remains to be done in the various departments, production centers, and machines on a specified date. Figure 2 shows a load chart for a foundry. At the left of the sheet, the classes or groups of operators, machines, and production centers are listed. In the next column the number of workers are listed for each group. The small numbers in the same column show the number of hours available per week for each group of men. The light lines show the number of hours assigned to each group in each of the weekly periods. When more than one light line appears in the same period for one group, the capacity is exceeded for that period and the department will be behind schedule unless additional help is given.

The foundry represented in this chart consisted of iron, steel, and brass molding departments and a core room. Each department was further subdivided as listed in the chart.

The chart² in Figure 2 indicates how the work ahead of the foundry stood on Monday, September 19. In the iron foundry there were 16 moulders on the crane floors, and since the foundry was

¹ *The Gantt Chart*, Wallace Clark, Chapter 7, Ronald Press, 1922.

² *Idem*.

running 40 hours per week, the moulding hours of these men per week amounted to 640. That amount was, therefore, used as a scale for each week. These moulders were at that time behind schedule on about 320 hours of work, which was represented by a heavy broken line through half of the first week. For that week there was scheduled on the Layout Charts, a little more than half a week's work. This was represented by a light line. For several succeeding weeks, the work scheduled amounted to less than half of the capacity of these moulders. The heavy line indicated the total time required to do the work assigned to them, that is, that it would have taken about $2\frac{1}{2}$ weeks to do all the work, if the men could have worked steadily at it.

The side floors had more moulders and enough work to keep them busy several weeks longer. The total capacity of the iron foundry, as indicated by the wider line, was taken up for $3\frac{1}{2}$ weeks.

The steel foundry, however, had a great deal more work ahead than could be done by the moulders assigned to that foundry. On the side floors, for instance, they were already about 3 weeks behind schedule, as indicated by the broken line, and for several weeks more work was scheduled than could be done by that number of moulders. There was a similar condition on the bench floors and the chart made it clear that unless more men were assigned to the steel foundry, the work would not be completed until December 3, although the last promise of delivery, indicated by light lines, was the week of November 6.

This chart emphasized the unbalanced condition of work in this foundry and the need for shifting workmen in such a way that all promises of delivery could be met.

The Z's on this chart indicate the week beyond which no work has been scheduled.

During 1947 the production control division of the Minneapolis-Honeywell Regulator Company developed a method of loading their machines which has been quite successful. The plan is essentially simple, is easy to maintain, and uses a minimum of personnel.

The basic plan uses a series of identical white cards except for the colored stripes near the top and bottom. The next operation determines the color of the stripe on the card which is used to post the load for the current operation. For instance, if the next operation on a part is drilling, the card on the current operation (say forming) has a yellow stripe just above the graduations which show the numbers of hours load.

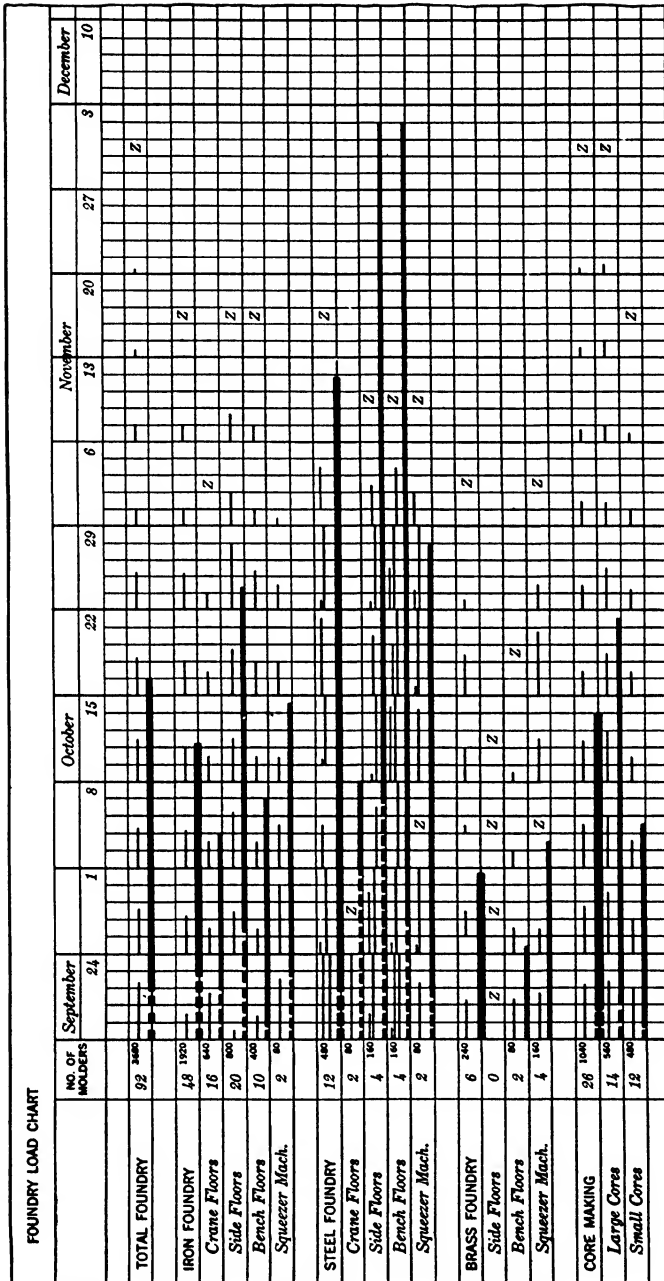


FIGURE 2. Gantt chart for a foundry.

In the punch press department the machine load chart uses the following color code to designate the next operation:

1. Red—punch press.
2. Blue—metal finishing.
3. Yellow—drill press.
4. Green—miscellaneous.
5. Black—move to stock.

For instance, if the current operation for any part on the board is charted with a black stripe, it means that the part will be finished

PART NO.	
THIS OP	
OPER. NO.	PREV. OP.
MFG. ORD. NO.	OP. LOAD
QUANT.	SETUP TIME
HR./M.	RUN TIME
RUN TIME	HR./M.
SETUP TIME	QUANT
OP. LOAD	MFG. ORD. NO.
PREV. OP.	NEXT OP.
THIS OP	OPER. NO.
PART NO.	

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FIGURE 3. Green stripe machine load basic card.

PART NO.	
34586	
OPER. NO.	NEXT OP.
4	
MFG. ORD. NO.	
4943/XT	
QUANT.	TIME
1500	
HR./M.	
1.43	
RUN TIME	
2.15	
SETUP TIME	
0	
OP. LOAD	ON. C.
2.5	
PREV. OP.	NEXT OP.
Form	Drill
THIS OP.	
Deburr	
4943/XT	

Minneapolis-Honeywell Regulator Co.

FIGURE 4. Machine load card posted from data on operation sheet and quantity to run. Note machine load of 2.5 hours assigned on lower right side of card.

with this operation; then the card will be moved from the board, the order will be closed, and the parts will be moved to the stockroom.

Figure 3 illustrates the basic card designed to show the load numerically and graphically. It is easy to chart 4 hours or less or from 4 to 8 hours on any card without destroying the fundamental data from which the load was determined. This card happened to have a green stripe.

Figure 4 shows the same type of card with a yellow stripe which has been posted from the data on the operation sheet portion of the manufacturing order. All posting on the card is done from the operation sheet except two items: (1) run time is the product of hrs/M times the quantity or number of pieces to be made for the manufacturing order, and (2) operating load is the sum of the run time and setup time (to the next one-half hour). The deburring operation on

PART NO.		34586		THIS OP.		PART NO.	
OPER. NO.		5		PREV. OP.		OPER. NO.	
MFG. ORD. NO.		49431 XT		OP. LOAD		MFG. ORD. NO.	
QUANT.		1500		SETUP TIME		QUANT.	
HR/M.		8.4		RUN TIME		HR/M.	
RUN TIME		12.6		HR/M.		RUN TIME	
SETUP TIME		.25		QUANT.		SETUP TIME	
OP. LOAD		13		MFG. ORD. NO.		OP. LOAD	
PREV. OP.		Deburr		OPER. NO.		PREV. OP.	
NEXT OP.		2 nd Form		THIS OP.		NEXT OP.	
Drill				PART NO.		THIS OP.	
49431 XT				49431 XT			

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FIGURE 5. Note 13 hours of load assigned to operation 5 at bottom.

this part required no setup time, so the total load on the machine used for deburring was posted 2.5 hours (actually 2.15 hours). Any loads which actually are less than one hour are posted as one hour. This eliminates small increments of load which are too small to affect the end result appreciably.

Figure 5 shows the load assigned to the drill press for the fifth operation on part number 34586 for manufacturing order number 49431XT. The sum of run time and setup time (to the next one-half hour) is 13 hours. One card, with the long stripe at the bottom, charts 8 hours, and with 5 hours cut from a second card the total of 13 hours is shown graphically on the board.

The machines are arranged in groups to do certain types of work such as slitting, blanking, forming, drilling, etc. These various groups may have the same sized punch press, but the same type press may be used for different purposes in the different groups. Thus the total

load for, say, blanking (up to 10 tons) would be assigned to the machine group and then charted to the individual machines in the group.

To conserve space each of the necessary cards to show the total load for a machine group is placed in a U-shaped celluloid holder with one leg of the U cemented to the back to a strong manilla paper flap (see Figure 6). The bottom edges of these flaps are spaced about $\frac{1}{2}$ inch apart on a vertical support behind the flaps. Remington-Rand

makes a Sched-U-Graph which may be used for holding load cards in the order of their scheduled dates. In order to hold enough cards to cover a week's work with two shifts (80 hours) for each machine, the chart length will have to be at least 30 inches for the cards (8 hours = 3 inches) plus about 2 inches for the legend for each machine on the left-hand side. The Sched-U-Graph is made with 50 or 100 flaps per board. Figure 7 illustrates how the active board may look at the close of the week for the P9 and D1 groups of machines. Within the limitations of this book page it would be difficult to show the entire width of the board legibly. Consequently, the board's area is broken into three convenient parts to show how the machine load is controlled.

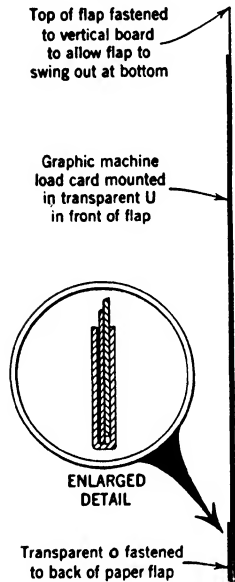


FIGURE 6. Diagram of device for holding machine load cards.

The capacity loads for the P9 and D1 groups shown in Figure 7 are 320 and 400 hours, respectively. This is shown on the chart by a black flag in the U holder in Figure 7. However, the actual scheduled load for the current week was 260 hours for the P9 group and 275 hours for the D1 group as shown by the yellow flags in Figure 7.

Monday of each week starts on the extreme right of the chart. Thus the work scheduled for Monday is shown on the extreme right and Friday's work is shown on the last 16 hours of the left side. Thus either a date line or red flags, as shown in Figure 7, can show at the end of the day or week whether any jobs are unfinished. For group P9, 20 hours were unfinished at the end of the week and for D1 group there was a 10-hour carryover into the next week.

At the Minneapolis-Honeywell Regulator Company, there are two complete charts for each machine and group of machines. The first chart is used to build up the load for the next week. During the current week, most of the adjustments are made in the schedule to meet

the changing demands and as the schedule becomes firm for, say, Monday of the next week, the cards are shifted to chart number 2. By the end of the current week the next week's schedule and load have become firm and are transferred to the final or number 2 board. No attempt is made to schedule 100 per cent of the theoretical time. At the time this study was made the scheduled load was from 60 to 70 per cent of the two shifts' capacity hours. This allows leeway for a limited number of emergencies without upsetting the entire schedule.

In addition to the current and next week's loads which are charted on the two graphic boards, the machine load department prepares

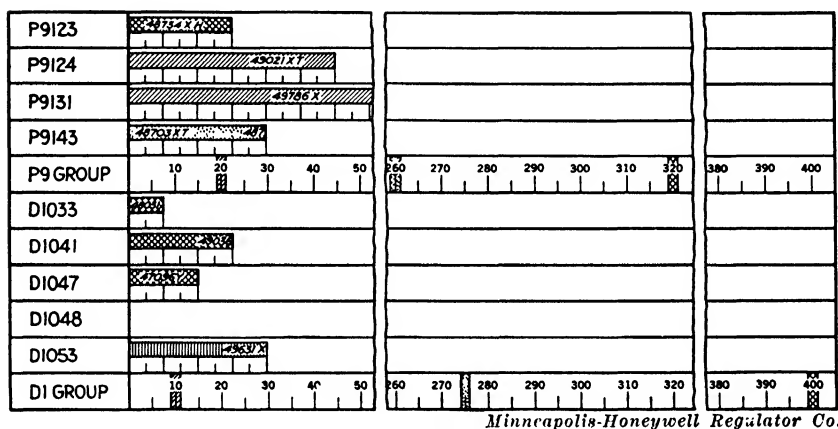


FIGURE 7. Graphic chart shows machine load at end of week.

the load cards and attaches them to manufacturing order releases which are beyond the board's scope. Sometimes these releases are three to four weeks in advance of their scheduled completion dates. However, since the cards, as shown in Figures 4 and 5, never have any dates on them, they can be prepared and moved to their chart according to their planned date or some other date if conditions change.

Production control would like to have schedules and machine loads frozen on some stated day, say two weeks before actual production starts. However, such an ideal condition seldom is realized, and most plans must be flexible enough to take care of the ordinary changes as they occur. The Minneapolis-Honeywell Regulator Company has a regular change procedure which makes the necessary adjustments in the machine load. These adjustments are made by groups or sub-groups within the group. Figure 8 is a plus or minus form which is placed above each current week's chart to post the changes as they

occur. When an additional load is added to any group, the manufacturing order number and its additional load is posted on the plus side of the form. At the same time the chart is changed if the load is sufficient and the notation on the form is crossed out but not erased. If the change is small for any machine or group, the machine load chart is not adjusted at once. The changes for any one group of machines are allowed to accumulate until they are significant before they are entered on the chart and crossed out on the form.

Adjustments or postponements sometimes have to be made because tools and dies are broken or damaged. If a machine group is loaded

GROUP	+				-			
1					48902XT Die broken 10 hours			
1B								
2	12		16		12		16	
9	49311X Quantity increased 2 hr							
9B	9	10	11	16	9	10	11	16

Minneapolis-Honeywell Regulator Co.

FIGURE 8. Form for posting changes.

almost to normal capacity, say 80 per cent, any machine breakdown in the group can cause delay in the scheduled machine load.

The machine load and schedule group has a telautograph installation between the several shops and the control office. The foremen can obtain information quickly regarding the next job scheduled for any machine and the control group can learn quickly when an order is finished so that it can be removed from the board.

Machine Load Reports. A periodic review of accumulated machine load data often will reveal valuable production facts. Table 1 shows several ratios such as

$$\frac{\text{Hours loaded at standard}}{\text{Capacity hours}}, \quad \frac{\text{Hours accomplished at standard}}{\text{Hours loaded at standard}},$$

and

$$\frac{\text{Hours accomplished at standard}}{\text{Capacity hours}}$$

These ratios are shown by machine groups, and the total hours are for all groups. This report, for the period it covers, shows that some

TABLE 1

RATIO OF LOADED HOURS AND ACCOMPLISHED HOURS TO CAPACITY HOURS

Group No.	Total capacity hours	Total hours loaded at standard	% loaded hours to capacity hours	Total hours accomplished at standard	% total hours accomplished to loaded hours	% total hours accomplished to capacity hours
Group 1	1,440	1,215	84.5	722	59.5	50.0
Group 1B	560	465	83.0	203	43.7	36.3
Group 2 P17	1,680	1,220	72.5	660	54.0	39.3
Group 2 P16	720	710	98.7	285	40.1	39.5
Group 9	400	165	41.3	105	63.6	26.3
Group 9B P10	80	20	25.0	...	....	....
Group 9B P9	160	13	8.1	7	53.8	4.4
Group 9B P11	240	138	57.5	42	30.4	17.5
Group 9B P16	240	115	48.0	96	83.3	42.6
Group 9B P18	80	...	....	...	....	....
Group 4	160	82	51.3	49	59.8	30.6
Group 5	160	66	41.3	42	63.5	26.2
Group 6	240	136	56.6	88	64.7	36.7
Group 6A P11	80	46	57.5	...	....	....
Group 6A P18	320	140	43.7	10	7.1	3.1
Group 6A P16	160	...	....	...	....	....
Group 6B P11	400	260	65.0	194	74.6	48.5
Group 6B P16	240	84	35.0	74	88.0	30.8
Group 9E	240	48	20.0	...	....	....
Group 7	400	360	90.0	299	83.2	74.8
Group 7A P10	80	42	52.5	20	47.7	25.0
Group 7A P11	400	186	46.5	78	42.0	19.5
Group 7A P16	400	195	48.7	125	64.2	31.2
Group 8	400	150	37.5	121	80.7	30.3
P9	320	120	37.4	112	93.4	35.0
Group 8C P10	160	126	79.0	86	68.2	53.8
P11	240	112	47.8	96	85.6	39.2
Group 8C P16	240	64	26.6	50	78.0	20.8
P18	160	16	10.0	16	100.0	10.0
	10,400 Total	6,294 Total	60.3 Ave.	3,580 Total	57.0 Ave.	34.4 Ave.

machine groups are actually being used as little as 3 or 4 per cent of their total capacity for two shifts. Even if their use were limited to one shift, the percentage would only be doubled to 6 and 8 per cent. This should be called to management's attention. It may mean that

the product has changed and no longer needs all the capacity in groups 6A P18 and 9B P9. The product using these groups may be seasonal and will use them again during their season. Shop executives may have overestimated the need for these two machine groups. In any event, the reasons for such small actual use of these groups should be studied to find remedial measures.

The over-all actual use factor of only 34.4 per cent of the available capacity for the period may suggest the necessity of one-shift operation, increasing the emphasis on sales, designing new products to use these machines, or selling the overcapacity in one way or another. Management can usually profit by carefully studying the data which are a by-product of a good machine loading procedure.

QUESTIONS AND PROBLEMS

1. How can machine loading procedure aid the sales department?
2. What factors tend to prevent using 100 per cent of a shop's capacity? Of a machine's capacity?
3. The steel industry during World War II often stated they were operating at 101 or more per cent of capacity. How could this be done?
4. What type of plants tend to have a low percentage of their capacity used?
5. What is meant by the economic use of capacity?
6. What effect does a fixed operational procedure have on the use of shop capacity?
7. Why should machine load reports be prepared for management's attention?
8. Make a machine load ledger for producing the motor shaft in Problem 7, Chapter XXI.

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CHAPTER XXIII

PRODUCTION CONTROL FORMS, THEIR PREPARATION AND DISTRIBUTION

There are literally thousands of different kinds of forms, charts, and devices used to control the flow of products through the different plants in America. As far as the author knows, there has been little if any attempt to standardize the forms used even for the same size and kind of industries. It is doubtful if any sweeping standardization could be made because the emphasis on the functions of production control varies considerably from one plant to another. Some plants require an expediting or followup organization to point out delays in production, while others, probably more thoroughly disciplined in the sanctity of a schedule, need little or no prodding to produce on schedule. Moreover, individuals in charge of production control are usually competent independent thinkers who are able to develop their own systems and to implement them with the necessary forms. The different methods of duplicating the necessary forms have also contributed to the variety of systems and their forms owing to advantages and limitations in the several methods. There is no national organization or magazine dedicated solely to the art and science of production control, and consequently more or less independent thinking has developed the many forms now used in American industry.

However, even if the forms have not developed along the same pattern for similar industries, the fundamental data written on the forms should be about the same. The shop executives, workmen, cost accounting, inventory control, and planning groups need official notice and guidance concerning such information as quantities to make, schedule to follow, materials to use, standard production per hour, setup time, and tools needed in order to initiate, control, and close a manufacturing order. This official information should always be presented in a clear, accurate, and consistent manner so that any group will know where to look for information concerning any order.

The information for any manufacturing order should be presented to all interested groups on as few forms as possible. Present duplicat-

ing equipment can make as many copies as necessary of any form but the ease of duplicating should not be an excuse for any extra copies. These several copies can be made on different colored paper for each group so that distribution by the messenger service is more accurate. A strange colored form in any department or group immediately signifies that the messenger service has made a mistake in delivery of the copies.

Cost of Unnecessary Forms. A common tendency in some plants is to prepare another form at the first opportunity. The forms themselves may cost very little more than the paper in them, but the cost of filling them out and later the cost of analyzing the data can become unnecessarily expensive, particularly if the data are of little or no value. This tendency to increase the number of forms is recognized by many good executives and they purposely make it difficult to set up new ones. Each proposed new form should be studied and compared with all similar existing forms to see if the proposed one is an actual improvement. If it can be shown that the new form will effect a saving in the collection or analysis of certain data or if it will convey certain information with less chance of mistakes, then it may be justified.

Forms Should Be Reviewed. In any event, existing forms should be reviewed from time to time to ascertain their usefulness. A three-hundred-room hotel employing about two hundred and fifty people at one time had over three hundred different forms which were used to systematize the business. A thorough study was made and, among other things, it was found that five different forms were in use for purchasing different materials. One form for purchasing all materials and supplies was developed to replace the five old ones. The many other forms were then regarded with suspicion, and they were studied carefully for overlapping and general usefulness. Out of the confusion about fifty emerged which are now regularly used to control the business.

The first test of a form's value is its continued use after its novelty has worn off. A more thorough test is to check from time to time to evaluate the importance of the data which is collected or the information it conveys. The importance of these data can be measured by the significant results which hinge upon their use. Excellent data can be collected, analyzed, and filed, but if nothing depends on them or if no consistent purpose is served the expense is not warranted.

Form Writing. The preparation of the manufacturing order to disseminate the information prepared by the production control department requires certain forms to do the best job. To a large degree,

these forms comprise the system which is used in the plant. They can provide a more or less automatic way to collect and convey information to all departments contributing to the manufacture and control of the product.

The variations in the arrangement and content of industrial forms are due to the personal opinions and experiences of the manufacturing executives, to the product itself, and to the methods used to manufacture it. As discussed in earlier chapters the same functions are more or less general to all manufacturing plants but the coordinating systems for these functions vary considerably. In one plant a particular function may require a large number of records and supporting data. Another plant making similar products, but having different policies, for example, in sales, will require practically no records for the same function.

Two companies manufactured competitive lines of a similar household appliance. One company's sales policy was to sell several hundred different models made from different combinations of standard parts. The other, instead of trying to make enough models to satisfy all conditions, selected about ten of the most popular models and concentrated on them. Both companies had about the same total sales volume but their sales policies were entirely different.

Both companies issued a manufacturing schedule twice a month. The first, which catered to all tastes, required about thirty people working overtime for a week to prepare and to issue the schedule of manufacturing orders for the next period. The second company, with its ten standard assemblies, required only a half-day's work of one clerk to prepare and issue the same type of schedule. Variation in sales policy, in this case, made a large difference in the scheduling function.

Similar differences may occur within the plants of an industry and certainly do occur between different industries. There are times when a function may require no records because some executive has grown up with the plant and carries all the information in his head. Generally, the smaller the plant, the easier it is for certain individuals to be trusted to remember to do the proper thing at the right time.

Forms for Production Control. When production control is used to its fullest extent, it may become rather involved. As plants grow larger the separate functions for controlling production become large enough to have their own specialists, and it becomes more necessary to depend on written data and records. The most common method of recording everyday routine information in modern industries is to use

a printed form. The form asks questions and provides space for the answers.

This interchange of pertinent data concerning current and future production in the shop should follow a consistent pattern to get the best results. Persons interested in such information should be able always to find the desired data on the same type of form which has been automatically delivered to the same place. This of course requires an adequate system to designate who should be responsible for entering the required data at the right time on the approved form. Moreover, the system should include a competent messenger service to deliver and collect the various forms to and from proper stations at designated intervals. Later in this chapter several such systems will be discussed.

Each function discussed in previous chapters was developed along with suggestions concerning the various types of forms needed for a systematic approach to the recording and presenting of the necessary pertinent information. The shape, color, or arrangement of the many forms suggested are not important in themselves but the type of data and information which they convey should be carefully studied to determine their usefulness for the problems at hand.

Therefore, this chapter is concerned primarily with the type of data and information necessary to release, issue, and deliver manufacturing orders to the production organization. In addition, it is necessary to collect performance data on production and inspection to close the order. Some of the form types used in this chapter were suggested in previous discussions; others will be developed in this chapter to coordinate, condense, and present the data for posting the final reports. The following outline presents a suggested list of forms which may be used for controlling factory operations after the sales forecast or order is released.

1. Forms for issuing and controlling manufacturing orders.
 - 1.1 Operation or route sheets.
 - 1.11 Accumulation of parts for assembly if stockroom is not used.
 - 1.2 Material requisitions for raw materials used in orders.
 - 1.21 One copy from stockroom to dispatcher to show in advance whether material will be available when needed.
 - 1.22 Another copy from stockroom to inventory control for posting the record, then to cost accounting if necessary.
 - 1.3 Identification tags for materials and parts in process.
 - 1.4 Dispatch orders for jobs released to shop.
 - 1.5 Tool notice and check, in advance, for gathering, releasing, and delivering to an operation just before it is scheduled to start.

- 1.6 Notification to make and release blueprints to be delivered to the proper dispatchers.
- 1.7 Shop inspector's report.
 - 1.71 One copy to inventory control, then to cost accounting if necessary.
 - 1.72 One copy to finished material stockroom.
- 1.8 Transfer or travel cards to notify move men to move materials and tools as required and later to notify dispatcher when they have been moved.
- 1.9 Central control records.
 - 1.91 Master schedules.
 - 1.92 Machine load records or charts.
 - 1.93 Dead-load file.
 - 1.94 Hold-up file.
 - 1.95 Blueprint file.
 - 1.96 Master file to show progress of order.
2. Cost accounting records.
 - 2.1 Job tickets.
 - 2.2 Labor costs.
 - 2.3 Material costs.
 - 2.4 Scrap report.
3. Inventory control.
 - 3.1 Purchase requisitions for production materials.
 - 3.2 Receiving reports for posting arrival of materials.
 - 3.3 Requisitions for materials or finished parts to post issues.

This outline lists the various types of forms usually used for each manufacturing order in a lot production plant. These forms should be distributed, according to the information they contain, to everyone in the organization who will have anything to do with any manufacturing order. Each such order is unique and must carry its own information even if it is for the same part which has been made in the very recent past. Many of the form types listed can be combined to reduce the total number of forms required. Moreover, each plant should be careful not to use any form which is not necessary for controlling the several steps of the process cycle in their plant.

Table 1 shows an outline of the usual basic information and to whom it should be delivered. Not all plants will need all the information shown nor will all the various groups be necessary in all cases. Smaller plants can combine the functions under one or more people, depending on the talents of the individual and the amount of work to be done. The outline in Table 1 is best used as an aid to decide which type of information should be included with the manufacturing order papers and to whom it should be sent.

TABLE 1
GROUPS BELOW WHO MAY USE THE INFORMATION ON MANUFACTURING ORDERS

	Inven- tory control	Schedul- ing and machine loads	Plan- ning	Dis- patchers and move men	Tool crib attend- ants	Superin- tendents and foremen	Time and motion study dept.	Work- men	In- spectors	Stock- room	Cost account- ing
Part number and name	x	x	x	x	x	x	x	x	x	x	x
Manufacturing order number	x	x	x	x	x	x		x	x	x	x
Quantity in order	x	x	x	x		x		x	x	x	x
Kind of material	x		x	x			x	x	x	x	x
Amount of material per 100 units	x		x								
Amount of material per order	x		x	x		x		x		x	x
Date material is needed	x	x	x	x		x		x		x	
Date finished lot is due	x	x	x	x		x		x		x	

Usual Types of Information on Manufacturing Orders

USUAL TYPES OF INFORMATION ON MANUFACTURING ORDERS

[illegible]

Operation Sheets as a Production Control Form. The routing or operation sheets discussed in Chapter XI are often an important source of information for good production control. The information on such sheets is usually the crystallized thought involved in deciding how each part or material is to be manufactured. These sheets should be the official information and guide to the most efficient method of doing the job. A number of forms are shown in Chapter XI, some of which are designed to be used as a basic form for the release of a manufacturing order. Figures 3, 4, and 5 in Chapter XI contain pertinent information valuable to production control for releasing orders. These three forms are not so complete for the use of production control as those shown in Figures 8, 9, 10, and 11 of Chapter XI. These four forms have a space block reserved for variable information which concerns only the current manufacturing order for that product.

The variable information block in the upper left-hand corner of Figure 8, Chapter XI, has space for the information necessary to issue a manufacturing order. Most of these items are variable from one order to another.

The manufacturing order number is a unique number for each succeeding order which is usually not repeated during the current year. It is a control number which is used to maintain a positive identification for all the various steps during the processing cycle. In some plants, it also serves as a number to collect material, labor, and overhead costs.

The part number is not a variable in this block, but it is repeated because the variable block is reproduced on other forms such as material requisitions and cost sheets to identify them positively with the manufacturing order number without the chance of clerical mistakes if the numbers were written in by hand.

The quantity in order is the number of units, pounds, etc., to be finished in the order. This quantity often is a variable in succeeding manufacturing orders for the same part.

The quantity of material units is the amount of material such as feet of 1-inch steel rod, castings, or pounds of flour to make the quantity in order. This quantity of material units is the amount requisitioned from the stockroom and may call for more castings than finished pieces wanted. The material overage item in the block is the average scrap made during past orders for the same unit. If the overage has been 3 per cent, the number of castings requisitioned from the stockroom would be 309 to provide enough for an order for 300 finished parts.

Material wanted gives the date specified by the scheduler upon which the material should be delivered to its first operation. Usually the material is delivered by a move man.

The day released is the date the manufacturing order is prepared by production control. This date should normally be early enough to include the full lead time for an orderly procedure for all the regular preliminary events before actual production starts. In fact, if most of the manufacturing orders are thus released there usually will be shop capacity and executive time available to take care of the occasional rush orders.

The date due should be a realistic date of when the part is actually needed to allow an orderly procedure for assembly or use. If due dates are set too far in advance of actual need, working capital is unnecessarily tied up too soon. Shop discipline may be affected if foremen find that none of the parts have been used even several weeks after the parts were completed on schedule.

The "released by" and "scheduled by" blocks are for the signatures of the authorized persons who have prepared the variable information. They fix responsibility and provide a check on performance and possible need for additional instructions occasionally.

The date of latest print, where a file of prints is kept in the shop, is valuable to prevent defective parts being made owing to obsolete prints in the file.

The economic lot size tends to be a constant unless conditions of use or production are seriously changed. The effect of any changes on the economic lot size can be quickly checked by the use of the chart shown on page 448.

Figure 9 in Chapter XI has four additional variable items which list the hours schedule and starting date for each operation. These data are written by the scheduler "S. B." for the guidance of the dispatcher. On the right-hand side the dispatcher for each operation posts the actual starting date and places his signature.

Accumulation Stations. Some types of manufacturers, particularly those making large low-volume products, often do not store their finished parts but accumulate them near the point of sub- or final assembly. This generally reduces the material handling problem provided that these large parts are scheduled to arrive and actually be delivered about when they are needed. (Any necessary units off schedule, however, can tie up important manufacturing space during the unbalanced condition.) These accumulation points or stations are often written on the operation or route sheets as a part of the official manufacturing information for the various parts or subassem-

blies. If such information is not on the operation or route sheets, it should be included as a part of the instructions to the dispatcher for that order.

Figures 9 and 10 of Chapter XI show where the parts are to be accumulated after they are finished. Part number 7162-1 moves to

STANDARD OPERATION AND RATE CARD																																																																	
MASTER	ORDER NO.	PART NO.		QUANTITY	PART NO.		DRAWING NO.																																																										
	1462	4408-E		150	4408-E		LL-663																																																										
	DATE ISSUED	DATE W/NT D	AUTHORIZED BY		PART NAME																																																												
	6/16/38	6/22/38	L.E.C.		Threaded Screw																																																												
RAW MATERIAL					SIZE																																																												
14/56 COH Steel					1-3/4" RD x 4-1/3"																																																												
<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th>OPERATION</th> <th>DEPT</th> <th>MACHINE</th> <th colspan="2">DESCRIPTION OF OPERATION</th> <th>RATE PER 100</th> <th>SET UP RATE</th> <th>HOURS PER 100</th> <th>OUT PUT</th> <th>DATE COMPLETED</th> </tr> </thead> <tbody> <tr> <td>A</td> <td>1</td> <td>2</td> <td>14-B</td> <td>Cut Cap</td> <td>1.17</td> <td>.25</td> <td>1.2</td> <td></td> <td></td> </tr> <tr> <td>B</td> <td>2</td> <td>2</td> <td>14-C</td> <td>Turn Point</td> <td>.89</td> <td>.30</td> <td>9</td> <td></td> <td></td> </tr> <tr> <td>C</td> <td>3</td> <td>3</td> <td>16-L</td> <td>Cut Thread</td> <td>.95</td> <td>.15</td> <td>.6</td> <td></td> <td></td> </tr> <tr> <td>D</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> </tbody> </table>										OPERATION	DEPT	MACHINE	DESCRIPTION OF OPERATION		RATE PER 100	SET UP RATE	HOURS PER 100	OUT PUT	DATE COMPLETED	A	1	2	14-B	Cut Cap	1.17	.25	1.2			B	2	2	14-C	Turn Point	.89	.30	9			C	3	3	16-L	Cut Thread	.95	.15	.6			D															
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Ditto, Inc.

FIGURE 1. Operation sheet and material requisition. Variable information at the top is placed on all forms.

370 stores, and part number 02943-N for an agricultural implement goes to department 85 for assembly into composite number 859 NA. One thousand of the current order for 3,900 pieces are to be delivered to repairs. Thus the operation or route sheet may be used also to state where the parts or products for lot production should be accumulated for their next operation.

The sequence and description of the operations, along with the times for setup and production, the kind of material, and the special tools

required constitute constant data which do not change unless the design or method is changed.

If the operation sheets are used as a basic form to release manufacturing orders, the masters from which they are produced are usually on file either in the production control office or in the reproduction room, depending on the process of reproduction.

Information Regarding Materials for a Manufacturing Order. The need for accurate information regarding materials for a manufacturing order is obvious. The official source of such information is usually the

950-864-NA																																					
PART NO.	ORDER NO.	FOR COMPOSITE NO.	DESCRIPTION				P/A																														
02943-N	4725	859-NA	Safety Collar				110																														
DEL. TO RPRS 1000	PCS REQ'D 3900	SCHEDULE 4/28/48	ROUGH SIZE 7/8" Dia. X 1-5/16				FINISHED SIZE 1-1/8																														
DATE ISSUED 3/21/48	PAGE 1	M. O. NO & MACH 5 G # 1620	MATERIAL SPEC. CRS 1015-20		CUT FROM 126-75	PCS. PER BAR 85	WGT. PER BAR 20 1/2 lbs																														
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FIGURE 2. Material requisition for releasing raw material to the first operation.

design or specification department. However, when operation or route sheets are used as part of the manufacturing order paper they often carry data concerning materials which are taken from the official blueprints or specifications. It is important, therefore, to have all such data kept up to date on the operation sheet by carefully watching for any official changes in materials on any new blueprints and specifications.

Production control usually assumes the responsibility for having the raw material on hand when the first operation is ready to start. This may be done by having the dispatcher or the central control office write the requisition to get the material, or, to prevent hand writing, it is possible to have the material requisitions reproduced from a part of the operation sheet. (See Figures 1, 2, 3, and 4.) Such a requisition may be issued in duplicate so that one copy can remain in the stockroom as a receipt for issued goods while the other copy notifies the dispatcher that the material has been delivered to the machine for the first operation. Sometimes a triplicate copy is used to notify the dispatcher in advance of the scheduled first operation date that the

material will or cannot be delivered as requested. The triplicate copy is used where close scheduling and the lowest possible inventories are carried as a matter of policy to reduce costs.

When the material is withdrawn from the stockroom, the requisition form also is of particular interest to the inventory control and sometimes to the cost department. The completed form is returned from the storeroom by messenger to the inventory control record clerk who posts the issue. The clerk, in turn, may send the form to cost accounting where it can be used as a basis for charging the material to the job.

MATERIAL REQUISITION										OLD BALANCE		AMT. ORDERED		NEW BALANCE	
PART NAME Pivot Bearing				LOT 24950	QUAN. 500	START DATE 6/10/48		DUE DATE 6/30/48		JOB NO 7985		WORK ORDER NO 10007			
MATERIAL .156"-.001" Stn. Steel Type #416					SPEC NO 9601	CODE NO 1704	QUAN 2.6	UNIT lbs.	TOTAL	RATE	COST				
PART NO.	OPR. NO.	DEPT. NO.	MACHINE GROUP NO.	TOTAL OPR. HOURS		START DATE	DUE DATE	PIECES GOOD	PIECES REJECT	INSPECTOR	DATE				
24950	1	400		050		6/10/48	6/10/48								
SEND ABOVE LISTED MATERIAL TO THE DEPARTMENT FOR OPERATION NO. 1															
DATE DELIVERED <u>6/9</u>						DATE WANTED <u>6/9</u>									
SIGNED <u>JH</u> Form F 462 Storekeeper						SIGNED _____ Material Control									

FIGURE 3. Material requisition portion of work order number 10007.

Material Identification Forms. It usually is not advisable to transport or place unidentified or unrouted materials on the floor of a large department. There are many chances for the material to be misdirected, lost, or just held because no one in the shop knows anything about it. Misdirected, unused, or lost materials have a way of being pushed aside to make room for active processes. After production is behind schedule, a belated search may uncover the lost materials. Enough tags or stickers should be reproduced along with the original manufacturing order to identify the order adequately as it goes through the shop. To prevent hand writing, some plants use the variable information portion of the operation sheet master to reproduce as many identification tags as necessary for attaching to the raw material container or the material itself. Figure 5 illustrates a type of tag used for material identification. Note that it contains the same variable information as shown on Figures 3 and 8.

Dispatch Forms. At the same time the storeroom is notified of a pending order by the material requisition, the dispatch stations, which control the departments where the parts are to be processed, should be notified either by a copy of the operation sheet used for the manu-

Operation Sheet										SHEET 1 OF 1	
INFL. ORDER NO.	PART NO.	PART OR ASSEMBLY NAME	PART NAME	ECOM LOT SIZE	% MATERIAL OVERAGE	PART NO.					
QUANTITY IN ORDER	QUANTITY OF MATERIAL UNITS	MATERIAL WANTED	MATERIAL NAME	ORIGINAL BY	G.B.	DATE					
DATE RELEASED	RELEASED BY	DATE DUE	SCHOOL BY	APPROVED TOOL DESIGN	L.C.	PROD SUPT. G.T.M.					
5806	7182-1	Suction Tank Mounting Bracket	Bracket	300	3.5	7182-1					
300	Use Clippings	1/1/48	1/1/48	50227 - C.R.S. Sheet							
1/3/48	D.C.E.	1/8	A.B.S.	12/28/46							
<div style="text-align: center;"> <h1>REQUISITION</h1> </div>											
304	1.3	0.4	0.1	650	20	Clip corners					
1/7	0.7	0.2	0.1	650	25	Burr					
1/8	2.1	0.6	0.3	652	30	Form					
1/11	2.6	0.8	0.2	670	40	Drill two (2) holes					
1/15	2.8	0.9	0.1	670	50	Tap two (2) holes					
1/16	0.7	0.2	0.1	670	60	Burr					
1/16	-	-	-	500	70	Final inspection					

Figure 4. Requisition portion of a manufacturing order reproduced by the Ozalid process.

facturing order or by a special form. This advance information starts a series of preparations in the dispatcher's office which lines up the department to complete the order on schedule.

Tool Notice and Check Forms. The loss of productive capacity and wages caused by requiring mechanics to get the various jigs, fixtures, and other tools from the tool crib may be considerable in some shops. To prevent these losses it is possible either to have a complete file of operation sheets in the tool crib or to send a fresh reproduced operation sheet to the tool crib when each order is released to the dis-

RAW MATERIAL TAG											
PART NAME Pivot Bearing 24950				LOT 1	QUAN 500	START DATE 6/10/48	DUE DATE 6/30/48	JOB NO 7985	WORK ORDER NO 10007		
MATERIAL .156"- .001" Stn. Steel Type #416					SPEC NO 9601	CODE NO 1704	QUAN 2.6	UNIT lbs.	TOTAL	RATE	COST
PART NO.	OPR NO.	DEPT NO.	MACHINE GROUP NO.	TOTAL OPR HOURS	START DATE	DUE DATE	PIECES GOOD	PIECES REJECT	INSPECTOR	DATE	
24950	1	400		050	6/10/48	6/10/48					
DELIVER THIS MATERIAL TO THE DEPARTMENT FOR OPERATION NO. 1											
Form F468											

FIGURE 5. Tag used to identify the raw material delivered to the first operation.

patcher. Upon receipt of the advance notice of a manufacturing order, the tool crib attendant can check the availability and location of the necessary special and regular small tools for that job. Thus the tools can be assembled, checked for condition, and delivered to the point of use by the move man upon final notice from the dispatcher who knows when the new job is about to be set up.

If the tool crib attendant finds that some of the necessary tools for a scheduled job are lost or not in condition, he should notify the dispatcher at once so that proper action may be initiated either to get the tools ready or to postpone the operation to a later date. If no one knows that the tools are not ready or that they are out on another job when the mechanic calls for them, the resulting confusion and loss of machine and mechanic's time is pure waste which cannot be recovered.

Figure 6 is an example of a tool withdrawal form. The dispatcher fills in the tool numbers of the various tools required for any given operation. The move man, with a transfer ticket and with the tool slip as authority, gets the tools from the crib and delivers them to the machine designated by the dispatcher on the transfer ticket. The tool

crib attendant fills in the date withdrawn, date returned, and issued by, and notes the condition of the tool when it is returned. If the condition is unsatisfactory, the tool is repaired or replaced to prepare it for the next run. The number of tool withdrawal slips required for any manufacturing order is shown in the form illustrated in Figure 20.

Request for Blueprint Release Forms. When blueprints or other information such as formulas, templates, patterns, and specifications are necessary, the blueprint room or others responsible for the correctness

NO. PCS. 2,000		OF TOTAL 12,000		START DATE 9/26/47		DUE DATE 12/9/48		WORK ORDER NO. 1005		PART NAME Feed Driving Eccentric		PART NO. 15303	
ASSEM. NO. 15303-A		DRAWING NO. 26433		CUST. ORDER NO. 8312		OUR S/O NO. 6790		CUSTOMER Leader Manufacturing Co.		LOT NO. 1			
AMT. REQ. 2,000		AMT. ISSUED		RATE		TCOST		MATERIAL DESCRIPTION		Cast Grey Iron - Spec. #6401			

TOOL WITHDRAWAL SLIP

TOOL NUMBER	DATE WITHDRAWN	DATE RETURNED	ISSUED BY	TOOL CONDITION

OPERATION NO. _____ SIGNED _____ DISPATCHER _____

Form 1 3471-5C-9-45

FIGURE 6. Example of tool withdrawal slip used as a tool check.

of the information should receive advance notice to have the material ready for release on the date of the scheduled operation. If prints or other specifications cannot be available for the scheduled date, the dispatcher should be notified so that proper action can be taken to prevent loss of shop capacity.

Inspector's Report Form. Line or process inspection is done while the parts or materials are in the machines or after an operation has been completed. Such spot inspection is quite common in many plants, but a record should be made to fix responsibility if any checking must be done later. Figure 7 illustrates how such a record may be reproduced on the back of the shop's operation sheet. Double-coated Ozalid paper is used to reproduce the operation sheet and inspection summary on one piece of paper. Note the inspector's privately numbered stamp after each inspection which prevents forging of the inspector's signature. Figure 8 illustrates one type of an inspector's final report on a manufacturing order. The typed portion was reproduced by mimeograph on the five copies when the original order

INSPECTOR'S REPORT FORM

505

FINAL PART INSPECTION											
PART NAME Pivot Bearing 24950				LOT 1	QUAN 500	START DATE 6/10/48	DUE DATE 6/30/48	JOB NO 7985	WORK ORDER NO 10007		
MATERIAL .156" - .001" Stn. Steel Type # 416					SPEC NO 9601	CODE NO 1704	QUAN 2.6	UNIT lbs.	TOTAL	RATE	COST
PART NO.	OPR NO.	DEPT NO.	MACHINE GROUP NO.	TOTAL OPR HOURS	START DATE	DUE DATE	PIECES GOOD	PIECES REJECT	INSPECTOR	DATE	
24950	1	400		050	6/10/48	6/10/48					
24950	2	410		645	6/10/48	6/11/48					
24950	3	440		125	6/11/48	6/12/48					
24950	4	410	1269	12	500	6/14/48	6/15/48				
24950	5	410	1269	12	500	6/16/48	6/17/48				
24950	6	413	533	20	000	6/18/48	6/22/48				
24950	7	440		125	6/23/48	6/24/48					
24950	8	476		16	700	6/24/48	6/28/48				
24950	9	440		165	6/29/48	6/30/48					
24950	10	476		6	300	6/30/48	6/30/48				

DATE	QUAN SUBMIT'D	QUAN ACCT.	QUAN REJ	REJ TAG NO	REASON FOR REJECT	INSPECTOR
6/31	508	499	9	864	5-hole large 4-bad material	C.B.

Form F465 in quin

DISPATCHER

DATE	QUAN SUBMIT'D	QUAN ACCT.	QUAN REJ	REJ TAG NO	REASON FOR REJECT	INSPECTOR
6/31	508	499	9	864	5-hole large 4-bad material	C.B.

Form F465 in quin

INVENTORY CONTROL

DATE	QUAN SUBMIT'D	QUAN ACCT.	QUAN REJ	REJ TAG NO	REASON FOR REJECT	INSPECTOR
6/31	508	499	9	864	5-hole large 4-bad material	C.B.

Form F465 in quin

INSPECTION

DATE	QUAN SUBMIT'D	QUAN ACCT.	QUAN REJ	REJ TAG NO	REASON FOR REJECT	INSPECTOR
6/31	508	499	9	864	5-hole large 4-bad material	C.B.

Form F465 in quin

COST DEPT.

DATE	QUAN SUBMIT'D	QUAN ACCT.	QUAN REJ	REJ TAG NO	REASON FOR REJECT	INSPECTOR
6/31	508	499	9	864	5-hole large 4-bad material	C.B.

Form F465 in quin

STOCKROOM

FIGURE 8. Inspection report on work order 10007.

was prepared. The copies were distributed by messenger to the dispatcher, inventory control, inspection, cost department, and stockroom. These groups are those usually interested when an order is closed. The penciled notations on the bottom are reproduced on the five copies by the inspector through the carbon backing on the first four forms. Sometimes the number of copies of the inspection report can be reduced by rerouting the copies after the information is posted. The control on possible missing copies is then based on the succession of manufacturing order numbers and accounting for the total number of pieces called for in the original order.

Finished Material Stockroom Form. When finished parts or materials are stored under different management than raw materials, it is often desirable to send an advance notice when an order is placed in the shop. Thus the finished stockroom will know when the new order is due and commitments can be made on that basis. A copy of the final inspection report is often sent to the stockroom with the finished goods as an official count of the good pieces turned over to the stockroom. This of course is subject to check by the stockroom at any time.

Material Movement Forms. It is expensive to require mechanics and machine operators to move their materials from one process center to another. The loss of productive capacity and wages under such conditions may cost considerably more than having regular move men or conveyers to move the materials from place to place. When move men are controlled by the dispatchers, materials are promptly moved as required. In some plants, there is so much material coming into the various departments from other buildings under the control of other dispatchers that it must be held in receiving bays. The current dispatcher should receive a copy of the move or transfer ticket delivered to him by the move man to show that the material is ready for use. (See Chapter XXIV.) The department dispatcher thus knows when material arrives from the stockrooms or other departments and can order it delivered for the first operation in the department on the scheduled day.

Figure 9 illustrates a type of transfer ticket used in some plants to instruct the move man to transfer raw, process, or finished materials to the designated department or process center. These transfer tickets are prepared in triplicate by the dispatcher for each movement of material from one process center to another. The original copy remains with the transferring dispatcher as his record. If the transfer is to another dispatch station, the duplicate copy is given to the receiving dispatcher by the move man as notice that the material is under

his control. The triplicate copy remains in the tote box, material-moving truck, or pallet as an identification until the next operation is completed. However, if a manufacturing order is split, for any reason, to allow a *partial delivery to the stockroom*, the triplicate copy is not destroyed but is used by the stock clerk to denote the number of pieces in the quantity received box and he also affixes his initials. This figure then becomes the official count when the triplicate is returned to the dispatcher of the last operation. The dispatcher records

TRANSFER TICKET		(DUPLICATE)	
Mfg. Order No. _____		Date _____	
Part No. _____		Last Operation No. _____	
Process Center No. _____		Process Center No. _____	
Move From	To		
Department No. _____	Department No. _____		
Total previously delivered _____			
Quant. delivered this move _____		Quantity Rec'd _____	
Total delivered to date _____		Stock clerk _____	
Transferring dispatcher _____			
Move man _____		Inspector _____	

FIGURE 9. Record of material movement.

the partial shipment to the stockroom on his dispatcher's copy which is reproduced on the back of the operation sheet. (See Figure 10.) The dispatcher then initials the triplicate copy and sends it to cost accounting as a record of the partial delivery. (See Figure 1 of Chapter XVI.)

The key information on Figure 9 for the move man is the manufacturing order number, the last operation number, the quantity delivered this lot, and the department from which and to which the material is moved. After the move is completed the move man initials the ticket and places the transfer ticket in the jobs moved pocket at the dispatch station. See page 538.

Central Control Record Forms. Whether all the functions of production control are handled by one large central organization or by several smaller organizations does not make very much difference so long as goods are produced at the lowest cost and on schedule. Any production control method starts with the design or specification engi-

neer's drawings or specifications and ends with the delivery of the final product to the shipping room. Critics of the large central organization claim that the checks and counterchecks provided by the equal-ranking, ambitious leaders of the several smaller planning groups are assets which are worth more than the possible extra cost involved. Companies that have one central organization in charge of all planning and control claim that better cooperation with more prompt action is possible with less overhead cost. Moreover, the proponents for central organizations claim less confusion and "buck-passing" where responsibility cannot be dodged.

Organizations of this kind have often been built around men who have developed certain skills and organizing ability. As more trained men appreciate production control problems, the tendency toward the larger central organizations probably will grow.

Decentralized Control. The fully decentralized method of control is the direct opposite of the method discussed above. In this plan the foreman and superintendent are the centers of responsibility. Each division or department of the plant has its own method of producing its products, subject only to an over-all due date usually set by the sales division for the completed parts or products. When the division or department is large, the task of planning and preparing for supervision of production becomes so great that a planning section must be set up. Individual planning sections may develop in each major department or division with possible confusion arising from the different methods of control.

Control Should Be Custom Designed. Between the two extremes of fully centralized and wholly decentralized control, there are a number of combinations which may be designed to fit certain plants. One plan about midway between the two extremes could have a central planning group to receive and analyze all orders to be manufactured. It could arrange the schedule and set the number of units to be produced by each shop department. Within the shop, the department's organization could control the movements of the work to meet the scheduled delivery dates. In addition, the shop could furnish reports at frequent intervals to the central group to show progress or the lack of it. This type of organization provides a measure of central control and yet allows a flexibility within the shop to give the foreman a chance to adjust his department to the daily demands.

The type of organization selected to control production should be the one that does the best job with the least expense. In some very complex production problems, the organization for control may involve some experimentation before suitable methods and a system of

control are developed. This is why the industrial engineer must study and understand the various functions of control and their importance and bearing on the situation at hand.

Central Control over Master Schedules. If a plant makes any attempt to have a measure of central control over the master schedule, it should consider a method of keeping progress reports and control over the release of manufacturing orders to the shop. Where the plant has several dispatching stations, it is a good plan to have a chief dispatcher (see Chapter XXIV, page 544) to maintain a uniform system in all dispatch stations. In addition, the chief dispatcher should be in charge of the several files in the central office which control and record the releasing of work to the shop departments in accord with the master schedules.

Machine Load Records or Charts. The problem of maintaining an accurate machine load to show how much shop capacity has been absorbed with the current scheduled production program is discussed in Chapter XXII. Several methods are explained and their necessary forms are illustrated.

Dead-Load File. The central control office ordinarily maintains a file of work orders which have been completely planned and prepared for release when desired, as the material and tools become available. This file of prepared orders is known as the backlog or dead-load file. Prepared orders are filed according to the dates on which the material is scheduled to arrive and then according to the part number under each date. As raw material arrival notices are received from the stores division, the notices are clipped to the order. Thus, at a glance, one may check several days ahead to see which orders do not have the raw material ready to start work on the scheduled date.

Hold-Up File. If the material has not arrived by the scheduled starting date, the order is sometimes removed from the backlog file and placed in a delayed-work or hold-up file. Orders are filed here according to part number. There is no point in sending any manufacturing orders to the department dispatch station if something is incomplete. Lack of material or lack of any necessary blueprints, specifications, or tools are equally able to prevent operations in the shop. The dispatch stations can function better if they are not cluttered up with a group of stalled jobs. In fact, many companies require that the dispatchers send back to the central office the prints and all the papers for any job which becomes stalled. Here they are placed in the hold-up file with remarks attached. Thus the central office has knowledge of all jobs that have been delayed, and it is easy to work out a code to state the reason for the delay. This technique is much

cheaper and many times more effective in locating and expediting delayed orders than a group of chasers looking all over the shops for them.

Both the dead-load and the hold-up files may need to store a considerable number of paper forms. These are best stored in folders or envelopes to keep all the material together for each order.

Blueprint File. Since blueprints may be quite bulky, they generally are filed separately in close proximity to the dead-load and hold-up files. A central print file is easier and cheaper to maintain than separate files of prints in each contributing manufacturing department. Unless a department uses the print continuously, it is foolish to maintain complete files in a number of places. Central files can be guarded to prevent unauthorized changes and, when the drafting department does make a change on a print, there is no chance of forgetting to destroy the old print in some remote shop file. When the order is completely ready to go, the prints are pulled out of the central files and sent to the dispatch station along with the manufacturing orders. Thus the shop always has the current print which travels with the order.

Master File. For many reasons, some shops like to know the status of an order from time to time. Anxious customers may be worried about getting the goods on the scheduled date. The plant may also be particularly anxious to keep in touch with certain jobs because of penalty contracts, public emergencies, and department prestige. Several methods have been used to keep a running account of the movement of orders through the plant.

If it is desired to keep a detailed record of all events in the progress of an order before and after it leaves the central office, a master file containing a special form to record every step is maintained. The form is prepared and sent to the central office when the other forms are prepared for the manufacturing order. The master file forms are filed according to part number. Every order to or from the dispatch station is passed over the master file first. If any orders are returned to the central office because of delay they are first passed over the master file. Thus this file shows a history of the events which have transpired from the time the order was first planned until it is completed. The events can be coded and placed in sequence on the card. Nothing should be erased but simply crossed out when the event is finished so that a complete record remains.

This kind of a record does not take very much room and can easily be posted, along with others, by the chief dispatcher. It shows where any order happens to be when an inquiry is made. It can be posted

in considerable detail if the orders and returns are likewise in detail.

Posting Costs from Planning Records. Chapter XVI is concerned mostly with planning records as a medium for gathering cost information. Cost records, to have a maximum value, should be current and not historical. In fact, the quicker the records of cost are made available after an order is completed, the more valuable this record

ORDER NO. 1468 PART NO. 4408-E QUANTITY 150 PART NO. 4408-E DRAWING NO. LL-668
DATE ISSUED 6/16/38 DATE W'NT'D 6/28/38 AUTHORIZED BY L.E.C. PART NAME 14/56 COH Steel SIZE Threaded Screw
RAW MATERIAL 1-3/4" RD x 4-1/3"

PRODUCTIVE LABOR CARD

OPERATION	DEPT	MACHINE	DESCRIPTION OF OPERATION	RATE PER 100	SET UP RATE	HOURS PER 100	OUT PUT	DATE COMPLETED
1	8	14-B	Cut Cap	1.17	.25	12		

PRODUCTIVE LABOR CARD

OPERATION	DEPT	MACHINE	DESCRIPTION OF OPERATION	RATE PER 100	SET UP RATE	HOURS PER 100	OUT PUT	DATE COMPLETED
2	2	14-C	Turn Point	.89	30	9		

PRODUCTIVE LABOR CARD

OPERATION	DEPT	MACHINE	DESCRIPTION OF OPERATION	RATE PER 100	SET UP RATE	HOURS PER 100	OUT PUT	DATE COMPLETED
3	3	16-L	Cut Thread	.95	15	6		

Ditto, Inc.

FIGURE 11. Constant data on the bottom of these forms can be placed as desired.

becomes as a control on the cost of a future order. Historical costs, on the other hand, which are available only after a considerable time has elapsed, may be too far removed from current conditions to be of much value in guiding current performance. The successful executive is interested in present conditions and trends which indicate future changes.

Labor Tickets. Figure 11 illustrates a method of duplicating productive labor cards by the ditto process which is excellent if the correct number of cards for the production can be estimated correctly. Some cost accountants insist on closing each card out at the end of the day and punching in on a new one the following morning. Others

use the last working day of the week as the cutoff point for the labor or job cards. If the prediction of the number of necessary labor cards becomes difficult it is better to have the dispatcher write the labor cards by hand and hold him responsible for entering the correct information.

Labor Cost and Payroll Data. Perhaps one of the most useful applications of a system of coordinated forms is in payroll procedure. Each workman on all operations is usually given some form of payroll voucher for recording time and labor cost for the operation. The dispatcher should receive these forms along with the other papers for the manufacturing order when it comes from the central office. When any operator calls for a new job the dispatcher punches in the starting time, and when the job is finished he punches out the finishing of the operation. For day work, the elapsed time is multiplied by the rate to get the labor cost of the operation.

When the job is on an incentive wage, the payroll voucher may have several attached carbon copies for different purposes. The dispatcher again punches in and punches out each voucher to get the starting and finishing time to compute the labor cost. The dispatcher multiplies the piecework rate by the quantity produced and enters the labor cost on the voucher. One copy should go to the operator for his record of work done, one copy to the payroll and cost department, and sometimes a copy is sent to the scheduling or central office to show progress.

As soon as these vouchers are completed, the dispatcher places them in a compartment for the messenger. Since messengers usually are scheduled to make several trips per day these cost data are not held up in the dispatch station. These data are coming into the cost and payroll departments continually, so that the clerical staff does not have peak loads at the end of the week.

Figure 12 shows a McBee Keysort job time card which has been printed with the necessary variable information by the Mimeograph process. Figure 20 shows that twenty-five of these cards are to be printed for work order number 1005. These are distributed to the proper dispatch stations where the dispatcher fills out the operation number, the account number, and the shift. The employee fills in his clock number and name and punches in and out for each assigned job.

If cost accounting for jobs or lot production is on an actual cost basis, a suggested form is shown in Figure 1, Chapter XVI. All labor, material, and overhead is posted on the form against the manufacturing order number as it accumulates. When any material or labor

is used on the job the dispatcher sends the material requisitions and labor tickets to cost accounting for posting. Since the manufacturing order variable information is printed on all forms used for any order in the upper left-hand corner, identification is easy and mistakes are eliminated. When the job is finished the cost has been accumulated.

Cost and payroll data, obtained from production control and regular administrative forms, are current information and are as accurate as possible. Little extra expense is involved in gathering these data in this manner as the information becomes a by-product of planning and planning records.

TENS		UNITS		TEN THOUSANDS		THOUSANDS		HUNDREDS		TENS		UNITS	
OPERATION NO.				PART NO.									
JOB TIME CARD - USE ONE CARD PER MAN, PER OPERATION				WORK ORDER NO. 1005						PART NAME Feed Driving Eccentric			
OPERATION NO.				ACCOUNT NO.						PART NO. 15303			
SHIFT				OUR S/O NO. 6790						CUSTOMER Leader Manufacturing Co.			
CLOCK NO.				MATERIAL DESCRIPTION Cast Grey Iron - Spec. # 6401						TLOT NO. 1			
EMPLOYEE NAME				LEADER MFG CO						CHICAGO, ILL			
REMARKS				TOTAL HOURS						HOURLY RATE			
GOOD PIECES				AMOUNT PAID						IN			
CLOCK NO.				WORK ORDER NO.						THOUSANDS			
UNITS				HUNDREDS						TENS			
TENS				UNITS						THOUSANDS			

FIGURE 12. Keysort job time card with the variable information reproduced by Mimeograph.

Material Cost. The material withdrawal or requisition card, sent by the raw materials stockroom to notify the dispatcher or the central office that the material is now at the machine, can also be used to supply the cost department with the amount and cost of the material. Likewise, the supply requisitions can be designed in triplicate to furnish information as a history to the department ordering the supplies, as a record and receipt for the storeroom, and as a charge for entry into the cost of a job or the budget of the requisitioning department. Such a correlation of records used by different departments can eliminate considerable duplication of clerical work and can expedite performance.

Scrap Report. A report on the amount of scrap, the actual net cost, and the person or department responsible for such scrap is discussed on page 346.

Inventory Control Forms. Inventory control is generally the beginning and the end of the production control cycle. The amount of

inventory to carry is determined by the rate of production, the economic lot size, the method of controlling the inventory, and the kind of work done in the plant. If production per day for the product is high, the parts inventory necessarily is also greater unless continuous production is the method of manufacturing. Lot production tends to increase inventory because there must be a carryover between lots.

The inventory record is generally posted from purchase requisitions and orders, receiving slips, material requisitions, and inspector's reports for finished manufacturing orders. Purchase requisition forms are discussed on pages 102-401 and they are illustrated in Figure 1 of Chapter VII and Figure 19 of Chapter XVIII. The record is generally posted (often by a special check mark) when the purchase requisition is issued to prevent issuing another requisition. When the purchase order is released the actual date and amount are posted (see Figures 5, 6, and 7, Chapter XIX) to show the material on order.

Receiving reports issued when vendors deliver materials as a result of a previous purchase order are used to post the inventory record to decrease the material on order and increase the amount on hand.

Requisitions for raw or finished materials delivered to the shop are generally issued as a part of the manufacturing order papers when the order is released. Figures 1, 2, 3, and 4 of this chapter illustrate different material requisitions which are a part of the regular forms prepared for each of their manufacturing orders.

PREPARATION OF MANUFACTURING ORDERS

The preparation of manufacturing orders is largely a matter of having the necessary constant and variable information arranged for the guidance of shop executives and workmen on all succeeding orders for the same part or material. The arrangement of such information varies considerably from one plant to another, but the fundamental data to be conveyed to and from the shop are quite similar in most plants.

Modern methods of duplicating short runs of typed or written material has made hand-written orders and returns from the shop too expensive except for the smaller plants. However, even in the smaller plants, the use of carbon-backed forms such as the McCaskey Register Company's system will reduce the amount of hand writing considerably. Small job shops producing single orders often hand write their routing sheets and other simple forms required to open and close the nonrepetitive orders.

Hectograph Methods of Duplicating Forms. The hectograph method uses a typewritten master made with an aniline ink. The gelatin-type hectograph transfers the information from the master to a gelatin pad which in turn is used to print the copies. Any hectograph master is quickly made. It also is easy to make corrections and changes by ordinary erasing procedures.

The old-style gelatin hectograph will not make so many copies from each master as the newer liquid-type machine. Moreover, the master can be used only once, and all the copies must be run in a few minutes or the ink soaks into the gelatin too far to print. There are several other disadvantages, but this cheaper type of duplicating apparatus can be used where only a few copies of an order are needed and where the orders are not repeated.

The liquid-type Ditto hectograph uses the same type of master with a slightly different ink. The master may be used, removed from the machine, and reused a number of times. One master will produce several hundred copies if all are run at once but something less than several hundred if it is stored a long time between a series of short runs. The master can be used longer and still give quite clear copies if it is stored in a waxed envelope to prevent smearing when it is off the machine.

Offset Printing Method of Duplicating Forms. The Multilith reproduction process, which is a product of the Addressograph-Multigraph Corporation, is a second method of reproducing production control forms which also uses a typed master. The process is an offset printing method of making as many copies as required. The master is a special matte which may have the form, such as a blank operation sheet, preprinted with a special ink on the matte. The constant information is then typed with a special ribbon in the regular spaces of the preprinted matte. The special inks used to make the master have an affinity for the printing ink whereas the bare master will not hold the printing ink. Thus the filled-out master is reproduced with black or colored printing ink to make clean sharp copies on any kind of blank paper.



Figure 13 illustrates a series of three forms used by the Gar Wood Industries for controlling production. These forms are reproduced by the Multilith process with the variable information typed for each manufacturing order on the variable master shown in Figure 14. All the forms for an order are placed in an envelope which is printed on one side with the same constant and variable information as shown in Figure 13. The other side of the envelope is used for an inspection report for each operation as shown in Figure 15.

The envelope with the enclosed forms travels with the parts and as the operations progress a count ticket is removed and sent to the chief dispatcher for entry on the control card.

[illegible]

Gar Wood Industries

FIGURE 13. Manufacturing order paper reproduced by the Multilith process.

2134165	2205998	2348943		DupliMAT	T6
MADE AND SOLD UNDER ONE OR MORE OF THE ABOVE PATENTS				TRADE MARK	REG U S PAT. OFF
					

Addressograph-Multigraph Corp.

FIGURE 14. Variable master used to reproduce the variable portion of the manufacturing order papers.

Mimeograph Method of Duplicating Forms. The Mimeograph process uses a die-impressed stencil to reproduce the blank form. The constant and variable information is stencil cut by the typewriter.

Figure 16 illustrates a form which is cut to contain the constant information for a certain part. This form is "die impressed" on a Mimeo-

Mimeograph Co.

FIGURE 17. Constant and variable information are combined on one form by the Mimeograph method.

Mimeograph Co.

FIGURE 18. Mimeograph stencil form pre-cut for variable information.

graph stencil and provides space for typewriter stencil cutting of the constant information as shown in Figure 17.

The variable information is stencil cut by typewriter on a die-impressed form as shown on Figure 18. The constant and variable

MATERIAL REQUISITION

NO. PCS 2,000	OF TOTAL 12,000	START DATE 9/26/47	DUE DATE 2/9/48
ASSEM. NO. 15303-A	DRAWING NO. 26433	CUST. ORDER NO. 8312	
AMT. REQ. 2,000	AMT. ISSUED	RATE	COST

Form 1.3452-SC-9-46

WORK ORDER NO. No. 1005	PART NAME Feed Driving Eccentric	PART NO. 15303
OUR S/D NO. 6790	CUSTOMER Leader Manufacturing Co.	LOT NO. 1
MATERIAL DESCRIPTION Cast Grey Iron - Spec. # 6401		

FINAL INSPECTION

DATE	TOTAL NUMBER PIECES	PIECES REJECTED	REJECT TAG NUMBER	PIECES GOOD

Form 1.3450-SC-9-46

Mimeograph Co.

FIGURE 19. Variable information for all production control forms can be reproduced by Mimeograph.

SCHEDULING RELEASE SHEET

NO. PCS 2,000	OF TOTAL 12,000	START DATE 9/26/47	DUE DATE 2/9/48
ASSEM. NO. 15303-A	DRAWING NO. 26433	CUST. ORDER NO. 8312	
AMT. REQ. 2,000	AMT. ISSUED	RATE	COST

WORK ORDER NO. No. 1005	PART NAME Feed Driving Eccentric	PART NO. 15303
OUR S/D NO. 6790	CUSTOMER Leader Manufacturing Co.	LOT NO. 1
MATERIAL DESCRIPTION Cast Grey Iron - Spec. # 6401		

SCHEDULING	WORK ORDERS	MATERIAL REQUISITION	TIME CARDS	TOOL WITHDRAWAL	INSPECTION	RECAP SHEET
1	14	2	25	6	3	1

Form 1.3472-SC-9-45

Mimeograph Co.

FIGURE 20. Schedule of forms to be released for each manufacturing order.

information forms are combined on the Mimeograph machine to reproduce the manufacturing order as shown on Figure 17.

VARIABLE MASTER		
FORM F-1345		
PART NO	ORDER NO	FOR COMPOSITE NO.
DEL. TO RPRS.	PCS. REQ'D	SCHEDULE
DATE ISSUED	PAGE	M.O. NO. & MACH.

Ditto, Inc.

FIGURE 21. Variable master for the Ditto process for duplicating manufacturing orders.



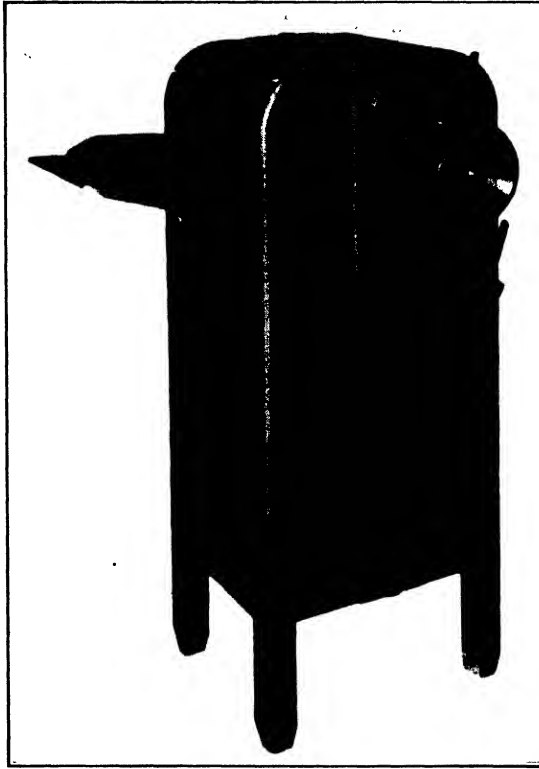
Ditto, Inc.

FIGURE 22. Machine parts can be controlled through a series of shop forms which requisition the material, route the work through successive steps in manufacture, and provide records for the office. By means of the Ditto machine each card is printed with only the information needed for its particular function.

The variable information portion of the manufacturing order is used to reproduce the material requisition and final inspection forms as shown in Figure 19. Figure 20 shows how the scheduler prepares the

variable information and the number of copies required of each form for the manufacturing order.

Constant and Variable Information. Most plants operating under the lot production plan can reproduce the constant and variable information for all the manufacturing order forms by any one of the three



Addressograph-Multigraph Corp.

FIGURE 23. Hand-fed Multilith machine for reproducing production control forms.

methods. A master is typed for each part to be made, which includes all the constant information such as illustrated in Figures 8, 9, 10, and 11 of Chapter XI.

These typed masters with the constant information are filed in numerical order for future use. When an order for a part is about to go into production, its large constant information master is withdrawn from the file and a master for the variable information (see Figures 14, 18, and 21) is typed for that particular order. The Ditto, Multilith, or Mimeograph machines can be arranged to transfer only that portion of the masters which is desired for a particular form.

Figure 22 illustrates the liquid Ditto machine, Figure 23 shows the Multilith machine. After the various papers for the order are prepared, the master sheet for the variable information is destroyed, as

710 <i>WHP</i>		DEPARTMENTS 400	LOCATION	
NO. PAGES 1	210,000 TABLETS NO. 241 BLANK, WHITE			
CUT				
ALTERATIONS O. K. BY	FINAL O. K. BY	R. S. ADDED	YIELD BULK	
	DATE	SCAGG MADE	STOP NO.	
T-KT REC'D - DATE	Milk sugar Lb. 39			
GOODS REC'D - DATE	Coupons inspected by _____ Date _____			
GOODS REC'D BY	Make on Colton machine using regular metal tablet mold (7/32" x 1/8") and alcohol S. D. No. 3-A, 50%.			
PRELIM. EXAM. BY	100 tablets should weigh approx. 130 grains.			
PRELIM EXAM. DATE	100 tablets do weigh _____ grains.			
DEL. FINISHED DATE	Wet down, about 4 fl. oz. for 5 lb. Amt. used _____			
FIN. STK. REC'D BY	No. weights on packer 6-9. No. used _____			
STK RECORDS - DATE	Made by _____ Date _____			
STK RECORDS BY	Wt. finished tablets _____ Wt. scag _____			
	Tablets soluble in _____			
REVISION DATE 7/16/35				
OUTPUT RECORDED				
COST SHEET CLOSED				
COPY CHECKED BY <i>WHP</i>				
APPROVED FOR INSPEC. BY				
APPROVED FOR INSPEC. BY				

Eli Lilly Co.

FIGURE 24(a). Operation sheet portion. The forms shown in Figures 24(a), 24(b), 24(c), 24(d), and others mentioned in text are parts of one long blue-printed strip.

it cannot be used again. The constant information master is replaced in the numerical file.

Blueprint Duplicating of Manufacturing Orders. The blueprint method of duplicating manufacturing orders is used by the Eli Lilly Company, manufacturers of pharmaceutical goods. Here manufacturing divisions must work with exact formulas which cannot vary

from order to order. The formulas are standardized and written in ink on tracings. The tracings are kept in a locked vault for secrecy and safety. All details of producing the product are written on the tracing, including the exact measurement and weight of all ingredients, techniques of compounding and mixing, and the final method of preparing the material. Some materials are left powdered, some are

SCHEDULE SHEET					H. T. Molding	
ITEM				LOT NO	QUANTITY	
Tablets Blank, White				No. 241	210,000	
OPERATION	SCHEDULE TIME ALLOWED	OPERATION COMPLETED	REASONS FOR DELAY	HISTORY OF TICKET	DATE	
	HOURS	DATE				
1. Move from (Chemical Drug) Stores	4	0		TICKET ISSUED		
2. Mold (Colton)	2	8		TICKET IN SHORT FILE		
3. Dry	4	0		SHORT		
4. Inspection	1	5		TICKET IN ROUTE FILE		
5.				TICKET SCHEDULED FOR MANUFACTURE		
6.				PRELIMINARY INSPECTION		
7.				MANUFACTURE OF TICKET COMPLETED		
8.				LENGTH OF PROCESS IN NO. OF DAYS	3	
9.				ACTUAL DAYS TICKET IN PROCESS		
10.				E 17 WRITTEN		
11.				PRODUCTION		
12.				O K SCHEDULE CLERK		
13.				O K SCHEDULE CLERK		
14.				EQUIPMENT TO BE USED		
15.				POT MILL		
16.				GRANULATION		
17. ○				MACHINE	Colton	
18.				DIES OR CUTTERS		
REMARKS:				PERCOLATER		
				TANKS		
				MOLD	Reg. Metal Tablet	

FH Lilly Co.

FIGURE 24(b). Schedule is made up for each order.

bottled as liquids, and others are pressed into tablets. Economic lot sizes have been calculated (see Chapter XX) for most of the company's products, and this quantity is placed on the tracing.

A large number of identifying tags are blueprinted at the same time so that the product can be well identified at all stages of manufacture. This precaution is very essential in this industry because many of the powdered white materials, for instance, may look alike.

The operation sheet is written on the schedule sheet end of the long blueprint strip. See Figure 24(a). The time allowed for each operation on the economic lot size of 210,000 tablets of milk sugar is shown on Figure 24(b). The scheduled times are typed in at the time the order is issued, and the form is used by the foreman of the shop to put the order through. See Figure 24(b). A portion of the strip

not shown in any of these figures is used to authorize the storeroom to release 39 pounds of milk sugar to make the order. Figure 24(c) shows the series of identification tags which travel with the order through the processing so that the material will always be identified positively. Figure 24(d) illustrates separate operation tags which are given to the foreman of each department to show him the scheduled time for each operation.

The main advantage of this method is the complete check the management has on the accuracy of all information. There is no chance

NAME TABLETS NO. 241 BLANK, WHITE		NAME TABLETS NO. 241 BLANK, WHITE	
AMOUNT		AMOUNT	EXAM BY
DATE	LOT NO.	DATE	LOT NO.
NAME TABLETS NO. 241 BLANK, WHITE		NAME TABLETS NO. 241 BLANK, WHITE	
AMOUNT		AMOUNT	
DATE	LOT NO.	DATE	LOT NO.
NAME TABLETS NO. 241 BLANK, WHITE		NAME	

Eli Lilly Co.

FIGURE 24(c). Identification slips for factory lots.

of a clerk's using the wrong master sheet for any manufacturing order.

Distribution of Forms. When the fundamental data for the manufacturing order have been prepared and the various forms have been duplicated, they must be distributed. Some of the forms are moved more than once and all of them must be either filed or destroyed.

Most plants use regular messengers to collect and deliver the various production control forms. The various forms must be clearly marked or their color must determine to whom they are to be delivered. Some of the largest lot production shops use air-tube or tel-autograph systems between the central office and the various production shops. This insures fast and frequent service for the distribution and collection of the production control forms.

Procedure Instructions. During the time a production control system is being developed in any plant, the movement of forms from station to station and within the stations should be carefully studied and recorded. The purpose of each form should be clearly stated and the

PRODUCTION CONTROL FORMS

MOLD		DEPT. NO. 400				
ITEM TABLETS #241, BLANK WHITE						
QUANTITY MOLDED		OPERATOR		O. K. DEPT. HEAD	M. & S.	
TIME ALLOWED HOURS		MOLDER NO.		TIME		
2.8				STOP START SEND TO COST DEPT.		
	START		COMPLETE			
	DAY	HOUR	DAY			HOUR
SCHEDULED						
PERFORMED						
DRY		DEPT. NO. 400				
ITEM TABLETS #241, BLANK WHITE						
QUANTITY MOLDED		OPERATOR		O. K. DEPT. HEAD	M. & S.	
TIME ALLOWED HOURS		MOLD NO.		TIME		
4.0				STOP START SEND TO M. & S. DEPT.		
	START		COMPLETE			
	DAY	HOUR	DAY			HOUR
SCHEDULED						
PERFORMED						
INSPECTION		DEPT. NO. 400				
ITEM TABLETS #241, BLANK WHITE						
YIELD		MONTH	DAY	HOUR	LOCATION	
READY FOR INSPECTION					PRELIMINARY INSPECTION	
					BY	
INSPECTED					FINAL INSPECTION	
					BY	

Eli Lilly Co.

FIGURE 24(d). Operation tags and schedule for each foreman concerned.

method of posting and using the data should be carefully explained. Most systems for controlling production require the cooperation of a number of different departments and people. If all of them understand their duties and responsibilities, the system will work with almost automatic precision.

It is desirable to present the various steps of the system in outline form to show where each form goes, who uses it, what it is used for, and its final disposition.

The following outline¹ is a *part* of the procedure which was developed to use the Ozalid process for reproducing the production control forms for a shop employing about 300 mechanics. Note how the procedure is outlined in detail so that if a new operator has to be trained he has complete instructions to follow.

- 1.5 Two Ozalid sepia transparent copies of the operation sheet are prepared and kept in a special file by the operation sheet group.
- 1.6 These sepia copies remain in the file. One will be withdrawn upon request from the scheduling group at the time when the order is to be issued (see 2.3).
2. Preparation of the manufacturing order in the scheduling office.
 - 2.1 The perpetual inventory record of each item is kept by production control. The balance of inventory is maintained by a regular posting of all orders, receipts, and disbursements of each individual part number at regular intervals each working day.
 - 2.2 Each part number has an inventory card showing its complete history and all data pertaining to ordering. A three-point control plan has been developed which establishes:
 - 2.21 A quantity known as reserve stock, below which point the stock is not expected to fall unless some emergency develops.
 - 2.22 A quantity known as order point, which indicates the inventory position at which an order should be prepared for the shop.
 - 2.23 An economic lot size, calculated on the forthcoming scheduled demand for the item and other factors.
 - 2.3 When the inventory figure comes down to the order point, the manufacturing order is prepared by withdrawing a sepia copy of the operation sheet from the file (see 1.6).
 - 2.4 The scheduler assigns and writes in the manufacturing order number, quantity in order, etc., as shown in Chapter XI, Figure 9, upper left-hand corner.
 - 2.5 Scheduler also determines from standard time data the dates upon which the order is scheduled to be run at each operation. He also writes in the total number of hours scheduled for the quantity on order.

¹G. T. Mitchell, Bruce Payne & Associates.

3. Printing of the necessary whiteprint copies on the Ozalid machine.
 - 3.1 The completed sepia copy of the operation sheet in item 2.5 is received by the print room.
 - 3.2 The machine operator prepares an original manufacturing order using 29-pound double-coated paper by using the sepia copy as a master for one side of the sheet and the standard inspection summary master for the back side of the sheet. An alternate method may be used by printing on two single-coated sheets and later stapling them together to form one sheet.
 - 3.3 The same process is followed for the preparation of a dispatcher's copy (see Figure 10) of the manufacturing order. Note that the

○ ○ ○					
REQUISITION					
AMT DEL	UNIT COST	TOTAL RAW	TOTAL FABR.	BACK ORDER	AMT. ORD.

FIGURE 25. Requisition master for reproducing manufacturing orders by the Ozalid process.

- front side of the sheet is an identical copy of the manufacturing order and the back side furnishes columns and lines for the dispatcher to record movement of the material through the shop. One copy is made for each dispatcher who processes the work order with the total depending upon the number of dispatch stations needed for the manufacturing order.
- 3.4 The Ozalid machine operator prepares the two copies of the requisition (black and maroon) by placing the punched and taped (see 3.51) foil strip marked "Requisition" (see Figure 25) on the front side of the sepia copy in the proper location and then proceeding to print the paper in the standard manner.
 - 3.41 Two 8½ x 11 inch sheets of single-coated standard Ozalid paper are used for the requisition. Two copies are made for use as follows:
 - a. The original or black-line copy to serve as cost accounting record of quantity issued (see Figure 4).
 - b. The second or maroon copy which remains in the stockroom or stores area as receipt for material issued.
 - 3.5 The machine operator cuts the sepia sheet as shown in Figure 26 and discards the larger portion of the sheet. The small sepia variable

master will appear on the cost record sheet and the back of the manufacturing order for the inspection summary and dispatcher's copy.

- 3.51 Three holes are punched along the top edge of the sepia strip by a hand paper punch. A strip of $\frac{1}{2}$ inch Scotch Cellulose Tape is stuck to the front side to cover the holes. When pressed down lightly over the holes from the front side the sepia strip will adhere to the correct spot on the cost record master. The sepia strip is easily removed and destroyed after the printing is done.


			
MFG. ORDER NO. 5606	PART NO. 7162-1	PART OR ASSEMBLY NAME Suction Tank Mount	
QUANTITY IN ORDER <i>300</i>	QUANTITY OF MATERIAL UNITS <i>Use Clippings</i>	MATERIAL WANTED <i>1/7/48</i>	
DAY RELEASED <i>1/3/48</i>	RELEASED BY <i>D.C.L.</i>	DATE DUE <i>1/18</i>	SCHDL DUE <i>A.B.</i>

FIGURE 26. Variable portion of manufacturing order used for the Ozalid process of duplicating orders.

This procedure is not shown here in full as it is meant only to show how such procedures may be written to explain the methods of reproducing the forms.

The success of any production control system will depend considerably on how well the plan is understood by the people who must use it. To train them originally and to provide the answers to most of the questions which will come up later, the entire step-by-step procedure should be explained in detail.² The following outline is a section of the procedure for handling manufacturing orders in a selected plant.

Figure 3, Block 7

Outlines the purpose of the operation sheet and manufacturing order. Note that the operation sheet has become a manufacturing order at the time the pertinent information is written on the left side of the sheet.

To start a manufacturing order in the shop, the worker punches out at the dispatcher's station on his previous job. The foreman assigns him to the next job available on the worker's particular machine or bench and has the dispatcher punch him in on a new job card. The worker also

² *Idem.*

receives his operation sheet (or manufacturing order) and blueprint drawing to enable him to begin work.

The manufacturing order travels through the shop along with the blueprint.

Upon completion of an operation, the worker returns the manufacturing order and blueprint to the dispatcher, punches out on the old job, and in on the new job. When any manufacturing order is partially or completely finished, the inspector checks the material as shown in item 7.8 and completes the process according to item 7.9.

The inspector returns the manufacturing order and blueprint by messenger to the dispatcher immediately upon completion of his final inspection operation. The dispatcher enters the necessary information on his office copy of the manufacturing order to show when all pieces are satisfactorily accounted for and the work is completed.

The real details are shown below.

7. Operation sheet or manufacturing order. First copy is the real manufacturing order which travels with the job. One additional copy for each dispatcher handling the order as a means of posting dispatching data only.
 - 7.1 Manufacturing order and copies are from the operation sheet for the part with the addition of the variable information for the particular order to be processed.
 - 7.2 This sheet is the only guide and central record for each manufacturing order.
 - 7.3 Copies received by each dispatcher about one week ahead of starting date.
 - 7.4 Operator or setup man uses the manufacturing order as a guide to do his work. Questions handled through the foreman.
 - 7.5 Inspector notes reverse side with any pieces scrapped during setup.
 - 7.6 Operator returns drawing and manufacturing order with work after completing his operation.
 - 7.7 Dispatcher issues new job card for the next operation.
 - 7.8 When pieces are finally finished and inspected, the inspector summarizes the information on the reverse side of manufacturing order and transfers the information to the inspection report. JC-501.
 - 7.9 Inspector returns completed manufacturing order and its blueprint, by messenger, to the dispatcher of the last operation after all pieces are accounted for.
 - 7.91 Dispatcher returns the manufacturing order and print to industrial engineering office for review.
 - 7.911 Standard time for each operation checked with actual performance hours.
 - 7.912 Were scheduled dates met?
 - 7.913 Reasons for and disposition of any scrap to complete the scrap report for the cost accounting.

- 7.92 All but the first copy of the manufacturing order can be destroyed.

Written procedures to cover every detail of production control system will answer most of the questions as they arise. The unusual questions can be answered by responsible persons in the production control organizations.

QUESTIONS AND PROBLEMS

1. Which comes first, the forms or the system?
2. Why should workmen and superintendents be interested more in points of information, as shown in Table 1, than planning?
3. What type of information is necessary for controlling the materials for a manufacturing order?
4. Discuss central versus decentralized control of production.
5. What are the merits of having dead-load and hold-up files?
6. Draw up a detailed procedure for preparing and presenting a report on how to schedule the preparation for manufacturing an ordinary spring type clothespin, from the original design to an order for 8,000 dozen.

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CHAPTER XXIV

DISPATCHING AND INTERNAL TRANSPORTATION

The planning and scheduling sections of the production control department work out all the control functions previous to their actual use in the shop. These plans are of no value, of course, unless they are actually in use and controlled by a representative of the production control department. The director of the preplanned procedure is the dispatcher. He releases work to the shop, directs its movements, and makes reports in accordance with the routing, scheduling, and other planning which has been done.

Dispatching for Continuous Industries. Dispatching in a continuous industry is almost automatic. Material flows from one operation to another with a minimum amount of control at the time the work is proceeding through the shop. The order of work is carefully planned when the production line is designed, and as long as all machines are working properly there is not much routine dispatching to do.

Dispatching for Lot Production. Any shop working on a lot production basis or any ordinary job shop, however, may have a very complex dispatching problem. Different jobs are routed over the same machines, and, when the shop is busy, there may be considerable confusion unless the work planned for the various machines is skillfully directed.

Dispatching has to be organized with a more or less flexible plan to be useful in most shops. Emergency jobs may appear at any time. If the planning and dispatching departments assume a rigid attitude towards emergencies, it will only be a matter of time until the shop will have to get along without a planning department. However, emergency and rush jobs should be analyzed. Moreover, an estimation of the cost of the extra effort to care for them should be made and reports of these extra costs should be made to the proper authorities. Occasionally, however, if the authorities believe that the emergencies are worth the extra costs involved, the production control department should include the extra work as a part of its regular duties.

In order to understand the situation, in most shops it is necessary to have the dispatcher in close contact with the foreman and the shop

conditions. Dispatching by remote control is not often wholly successful, because conditions can change too quickly. The usual method is to have the dispatcher located in the foreman's office, or preferably in a separate small room in the center of the area to be served.

Dispatcher's Relations with the Foreman. Dispatching is a service furnished by the production control division to assist shop executives in getting the various jobs out on schedule. Since it is a service function, the dispatcher must be the type of individual who can give certain directions to the workmen without interfering with the prerogatives or prestige of the foreman. Naturally, under this peculiar relationship the dispatcher must work in close cooperation with the foreman, but under *no* circumstances should he report to him. Rather, the dispatcher should be classed as an executive on a par with the foreman.

On the other hand, the foreman should not be allowed to ignore the plan which has been set up, and for whose execution the dispatcher is responsible. Through contact with the details of the machines and men under his jurisdiction, the foreman should know the operating conditions better than the dispatcher. Both executives must work together in close harmony as friendly critics of each other in order to get the work out on schedule. Arguments or controversies seldom will occur if the responsible men are properly selected. If they do, their superiors should settle the difficulties.

DISPATCHER'S RESPONSIBILITY

In general, the dispatcher is responsible for keeping both workmen and machines busy within the limits of the work which has been released to the shop. He is responsible for having the materials, tools, blueprints, and any other instruction data available for the workmen when the job is ready to start. When inspection is necessary at certain points he arranges for it by notifying the inspector to come to the job or by moving the job to the inspector. The dispatcher is always responsible for issuing the orders to move material from place to place as necessary to complete the scheduled operations.

Move Orders. It is not good practice to have machine operators or high-priced assembly mechanics move material to and from their work stations. The labor cost, when such men are used, is generally higher than that paid to internal transportation people. Often, the most serious expense involved is overlooked. When the machine operator or assembly man is not running his work station, he can produce nothing and such time is irretrievably lost. The total loss of produc-

tion due to the machine's enforced idleness means that the machines are not earning their share of the overhead cost nor are they making a profit.

Sometimes, when the machine operator is asked to move material, he welcomes the chance to leave his station and visit with other workmen which only means more idle machine time and a piling up of extra costs. It is far better to have controlled rest periods to relieve possible monotony than it is to allow uncontrolled visiting while the machine operator is moving material about the shop.

No internal transportation people, with the possible exception of traveling crane operators, should be allowed to move any material without a move order issued by the dispatcher's office. Since the dispatcher's board shows the location of material for certain orders at all times while the order is in the shop, it would be impossible to do this unless the dispatcher issued all the move orders.

An exception to the rule noted above should be made for large traveling cranes. Here the craneman's helper should look at the location of the next operation when he is called to lift a large piece from a machine. If the machine for the next operation is ready to receive the piece, the crane should deliver it even though the dispatcher has not issued a move order for it. When the move is completed, however, the craneman's helper must report it to the dispatcher's office.

Where the machine for the next operation is not ready, the crane-man will have to handle the piece twice, because cranes are usually so busy that they cannot hold a piece very long. The craneman should be allowed to set the piece down where it will be most easily picked up again when the next machine is ready to receive it.

Where crane service is necessary, the dispatcher cannot be ignored, but, because of heavy service demands on the crane, he may have to be notified of moves after they occur.

The general internal transportation department is usually responsible for all moves from the raw stores to the shipping room. In some companies, however, the GIT (general internal transportation) moves materials only from raw stores to incoming departmental bays and from outgoing bays to other incoming bays. Within the department all material is handled by a system of local transportation. Regardless of the system for moving materials, the transportation men should not move materials without authority to do so. These men should be carefully trained to see that all material in a lot is identified properly by comparing orders with the part numbers and quantity in the order.

Movers in this kind of a shop should be selected for more than just a strong back. They must be strong and alert and have respect for written orders.

Tool Orders. The tool crib attendant is responsible for knowing the tools required for all planned operations. The operation sheet or a special form is sometimes sent to the crib for the information of the tool clerk. He should get this information as soon as the planning department has it ready so that the availability and location of the tools can be written on the tool crib form. If the required tools are not on hand, there may be time to get them before the scheduled date. Otherwise the dispatcher should know far enough in advance of the scheduled date to make adjustments in the dispatching.

If all tools are available and none of them are too large to prevent the mechanic's carrying all of them in one trip, the crib attendant has them accumulated by the scheduled date and ready to issue when the mechanic calls for them. When tools are large or numerous, the tool crib may have them delivered by the regular transportation service just before the operation is ready to be set up.

Many companies print a tool check copy for every operation requiring tools of any kind. These checks are printed at the same time the other papers are being prepared for the manufacturing order. (See Chapter XXIII.) Since the tool crib has an accurate record of the tools required for all scheduled operations, it is not necessary for the machine operators to present their personal checks for every tool taken from the tool crib when these tools are used on scheduled operations. The printed check can be sent to the tool crib by the dispatcher several days before the tools are actually needed. This allows the crib attendant to accumulate them during slack periods, thus tending to iron out peak loads in the tool crib.

It is considered good practice to have the tool crib and the dispatch station as close together as possible. When the mechanic calls for his new job at the dispatch station, he can bring the tools used on the old job back on the same trip. Likewise, the tools required for the new job can be taken to the machine on the way back from the dispatch station. Thus setup time and costs are reduced by a planned procedure which saves considerable walking while setting up a job.

Material Orders. The dispatcher controls the movement of raw material to the first operation by issuing the stores order calling for delivery at the machine on the scheduled date.

When the material leaves the storeroom, one of the original copies of the storeroom order is sent by the stores department to the cost accounting department. Another copy is sent to the inventory con-

trol clerk. These forms were prepared and distributed with the other forms when the manufacturing order was originally printed. (See Chapter XXIII.) Thus, by the distribution of the initial manufacturing order papers, the stores department is notified in advance when raw material is needed and how much of it should be moved in this order. If the material is on hand the department simply acknowledges the order by a returned form, but if the material cannot be on hand at the scheduled date the returned form specifies when it may be expected. By procedures similar to this everyone who is concerned with material is kept informed about its movements and disposition up to the first operation in the shop. After that only the dispatcher, the shop, and the central planning department are interested in the material until it is ready to enter the finished stores.

Finished Stores Order. As a completed part or assembly, the order again becomes of interest to the stores division. The finished stores department, which is to receive the order, has been notified by the original distribution of the forms when the order may be expected. (See Chapter XXIII, page 506.) This notification should serve a dual purpose. The finished stores knows space will be required to store the order, and commitments against the new order usually can be made on or after the scheduled completion date.

The dispatcher thus controls the movements of raw, in-process, and finished materials within the limits of the schedule as closely as shop conditions will permit.

Additional Details for the Dispatcher. In fact, the dispatcher is responsible for a number of additional detailed operations which usually are a part of the system in the plant and which thus become more or less automatic. He receives all incoming planning material at his station from the messenger or air-tube delivery system. He meets all required scheduled dates or promptly asks for extensions with reasons for delay stated. He posts the dispatch board and dispatches the various jobs through the most economical process and machines available when the material is ready. He must report at frequent intervals to the central office concerning the progress and delays of the various jobs in process and waiting to be processed. Lack of tools, materials, instruction sheets, or blueprints may be the cause of serious delays and should be reported as soon as it is known that they are not going to be available on schedule. When the backlog of jobs for certain machines begins to run below normal, the dispatcher should notify the central office to release any available work for these machines. At times the dispatcher can reduce factory cost on small job runs (obviously below the economic lot size) by combining similar jobs when

they are scheduled closely together. Usually the dispatcher or someone in the dispatcher's office is also responsible for recording the proper labor time used on each job. The best way to insure that the proper time is charged to each order is not to issue any new jobs to any workman until he returns all the prints and instructions used on the previous job. In other words, the dispatcher should not allow an operator to work on more than one job at a time unless he is running several machines on different operations.

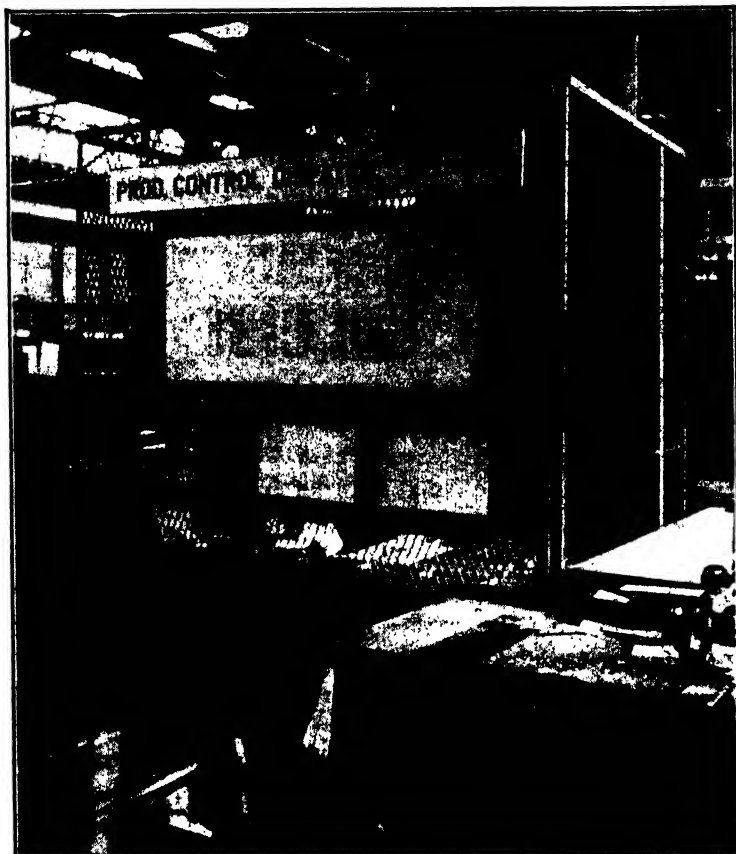
Dispatching Should Be Done Only by the Dispatcher. To prevent confusion, the dispatcher alone should be responsible for the above duties. If the foreman or any other member of the shop force is allowed to change scheduled dates or the sequence of operations without consultation with representatives of the production control department, chaos would result in a short time. The dispatcher must therefore do his work in an enclosed space where his records, instructions, blueprints, and orders are free from curious, meddling people. Space for dispatching seldom needs to be very large. Forty to sixty square feet of usable space is sufficient for most needs.

The Dispatch Station. It is customary to have a dispatch station in each department or one for about every fifty to one hundred men. If dispatch stations are too far apart, too much time is spent in walking to and from the station when jobs are changed. Most plants already have timekeepers, and, by selecting the proper persons and organizing a workable system, one man usually can do both the timekeeping and the dispatching for a medium-sized department.

The dispatch station should be equipped with a door which can be kept locked with only the dispatcher holding the key. In places where dust and noise do not create too great a problem, the station need be only a small space enclosed with wire mesh or expanded metal. The dispatcher thus can look in all directions and observe conditions in the shop with greater ease. Figures 1 and 2 illustrate a dispatch station used by the General Electric Company which contains all the essentials for good work. The operations in a dispatch station should be motion studied to get the best arrangement of the files, compartments in the desk, and other equipment which the dispatcher must use.

The various files and compartments necessary in the station will depend entirely on the system used for controlling production. Some plants require a blueprint file which is used to store active prints for jobs about to enter the shop. Compartments should be arranged on the desk for forms and other material received from and sent to the central planning department. A separate compartment for forms to

be sent to the payroll or cost department is also useful. Such pockets or compartments for forms to be returned can be used to store them when they have been completed by the dispatcher. When the messenger calls to deliver and pick up material there need be no waste



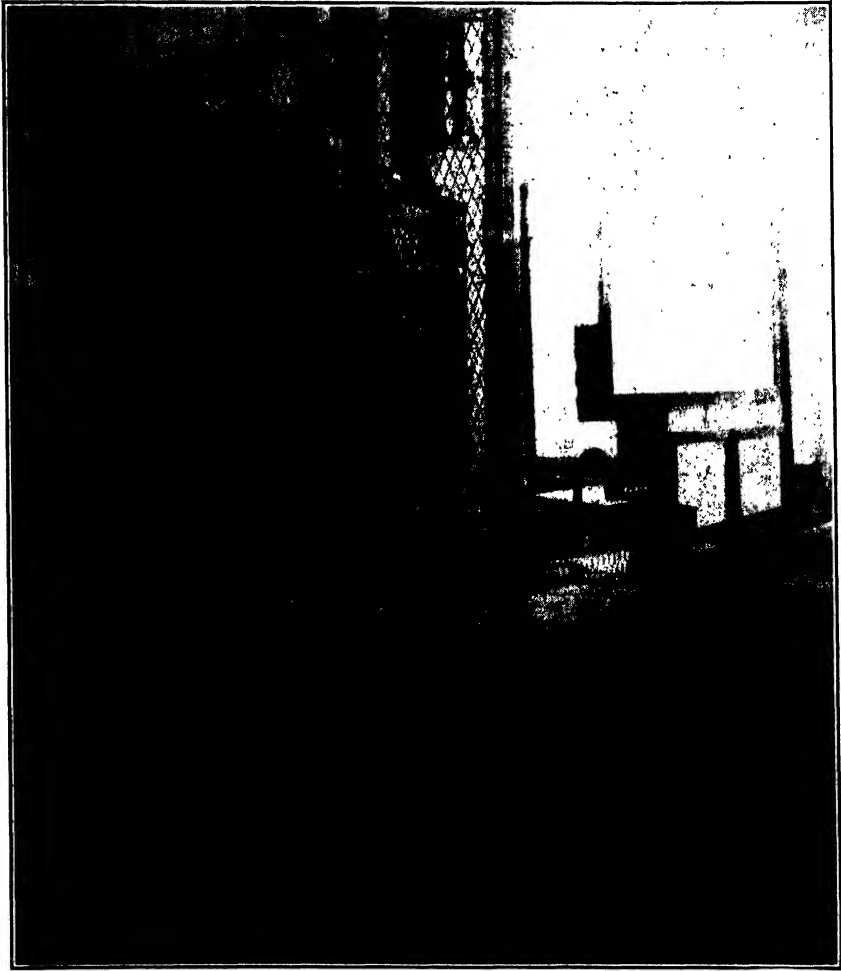
General Electric Co.

FIGURE 1. Dispatch Station Building 16. Schenectady plant of General Electric Co. Note layouts of department on front of station.

of time in getting the forms together. Moreover, departments such as payroll, cost accounting, inventory control, and transportation can get their information from the various dispatch stations as often as messengers call at the station. Thus, all such departments get their data continually and can work on an even load throughout the week.

Figures 1 and 2 show a large compartment attached to the end of the desk. This is for blueprints which are ready to be returned to the central file. Note also the three small boxes just outside the

small opening in the dispatch station. The boxes are labeled "jobs to be moved," "jobs to be priced," and "jobs moved." The dispatcher in this instance places the move cards for material to be moved in



General Electric Co.

FIGURE 2. Dispatch Station Building 16. Schenectady plant of General Electric Co. Note pockets in special desk and blueprint file.

the proper box. The transportation department, in making its regular trips around the department, drops the cards for material which has been moved into the proper box and picks up the new move orders for future transportation. The middle box is occasionally visited by the time study man to find which jobs need new time studies.

Dispatch Board. Most dispatch stations contain some record of current and available jobs for the machines in the jurisdiction of the station. This record is often graphic or visual in nature but it can be kept in a file box if space is limited. However, dispatching is much easier to follow if the graphic method is used. Each machine or work station is given a unique number which is used as a code on the dispatch board.

The simplest board consists of a hook or pocket for each production center. The card designating the current order in the machine is out

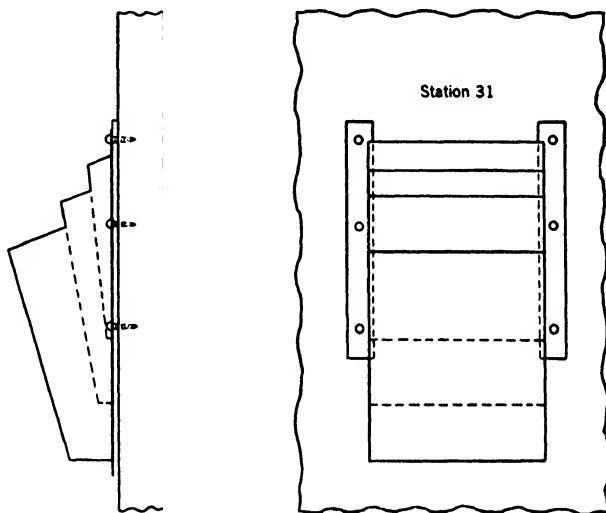


FIGURE 3. Three-pocket arrangement for dispatch board.

in front and the jobs next in line are placed in order next to the current outside card. This plan does not graphically present as much chance for control as does a two- or three-card plan for each production center. When three positions are used in a vertical line, the top card represents the current condition or job for the machine. The middle card shows the next job or situation when the current job is finished. The lowest position of the three is used to store all the available jobs released for that particular work station.

Though boards arranged with hooks are the simplest to make, the cards must have holes punched in them; this may not always be convenient. Many companies use small slanting metal pockets made from sheet metal which are nailed to the board. Space can be saved by this procedure and thus the boards for a large department can be smaller in size than when the cards are hung on hooks. Figure 3 illustrates one way to make these pockets in groups of three.

Sometimes a graphic system can be developed further to show what is happening at every station on the board. If all current job positions (top position) on the board are filled with job orders, all machines are running; but if, for instance, a yellow card is in the current position, the machine has no work. If the yellow card is in the second position, there is no work available when the current job is finished. When the machine is being repaired or is out of commission for any reason, another color can be used. Sometimes it is necessary to let a machine stand idle because no workman is available to run it. This could be shown with another color, say black. Sometimes, an operation for a part is run on several machines simultaneously. This can be shown by having duplicate work orders made for each machine, to be placed in the proper positions on the dispatch board. A better plan, from a graphical standpoint, uses a special card with a unique color and a written number which signifies that the machine is doing duplicate work which is also running on the numbered machine.

With little effort in the dispatcher's station, the condition of the shop's productive capacity may be seen at a glance. The various colored cards and the actual job cards placed on the board give a picture of the department which would require considerable time to get by means of an actual inspection of the shop. Moreover, it is a moving picture which changes continually as the conditions change.

As a further aid to good dispatching some companies use an operator's card at each station on the dispatch board. This card shows the current operator at the machine, but it also lists other machines this operator is capable of running well. In busy times, when absent help is sometimes a problem, the information on the cards concerning the operator's skills is invaluable for quick assignment of men to essential jobs which are temporarily without operators.

Accumulation before Assembly. Each dispatch board used in job shops where major sub- or final assemblies are made should have several work station numbers assigned to the accumulation. Accumulation can be planned the same as any other operation. If the schedule is planned according to Figure 1 in Chapter XXI, all the parts will be finished about the same time and can be delivered to the accumulation point with move cards controlled by the dispatcher. Sometimes, however, this ideal situation cannot be used and the parts are gathered from a variety of sources, including parts just finished and others which have been in stores for some time. The accumulation operation, then, is a job like any other operation and is performed by men who act upon notice from the dispatcher. The accumulation

can get under way when the last piece for an assembly is finished or when the assembly is needed for use elsewhere.

Eliminate Setup Allowances When Unnecessary. All dispatchers should be trained to eliminate unnecessary setup costs wherever possible. Under ordinary conditions the specified price for setup is paid whenever it occurs on the operation sheet. Many times, however, there are several manufacturing orders for the same operation going through the shop. The dispatcher should combine these orders whenever time or economic lot considerations will permit. All but one of the setup allowances for the combined orders should be canceled, thus reducing the setup cost.

Dispatcher's Control of Waiting Time. Sometimes operators, through no fault of their own, are required to stop their machines because something has gone wrong. They are forced to wait until the condition can be corrected. In the meantime the workman, if he is on an incentive wage, either loses his wage-earning power or he is compensated at some rate (usually lower than his normal earning power) during his enforced idleness. Some disastrous labor troubles have been attributed to a lack of control of waiting time by managements who expected incentive wage plans to stand this strain.

Where wage plans obviously include a large factor for lost time due to waiting or where straight day work is used, the cost of waiting time may be hidden. When men are working on day work, not many of them object to waiting as long as necessary to get production started. This, of course, is also a poor method to handle the problem of waiting time because it lacks any incentive for closer control. The management, in effect, thinks that since no waiting time is apparent in the costs there is none to worry about.

The inclusion of the average waiting time in the incentive wage system or the payment of regular day work, to be charged to the current order, simply neglects the loss due to waiting. A much better method is to notify all workmen to ask the foreman for waiting time forms after, say, the first five minutes of inactivity. These waiting forms are used as regular job tickets. The men punch out the regular job and punch in the waiting-time ticket. The dispatcher should run these waiting-time forms at the stations just the same as a regular job order. The dispatch board shows the machines and stations which are down owing to waiting and later these forms are analyzed for cause of the trouble. When the emergency is over the operator reverses the procedure and punches in on the regular job order.

Since a percentage of the waiting time is due to the foreman's mistakes, and since additional waiting time can be attributed to people

who are responsible to the foreman, he should sign all waiting-time tickets. The foreman usually gets a certain measure of enjoyment in signing for loss of time caused by the production control or dispatcher's office. Nevertheless, though the isolation of waiting time may seem expensive and the analysis of it may point to high places, it is one of the best ways to find and correct the continual loss from unnecessary waiting time.

Methods of Combating Waiting Time. An analysis of the reasons given on a series of waiting-time tickets showed that a large percentage of the trouble was due to assigning work to a station before all the blueprints, tools, and materials were at the work station. This, of course, is largely the responsibility of the dispatcher and can be easily corrected if the dispatching system is made to work properly. Where an incentive wage must be used on every job, the lack of a piece rate can hold up a job if it is a short one. If a time study man can make his study during the run, the rate can be retroactive from the first piece and thus no time need be lost. However, if the job is a short one, it is the dispatcher's responsibility to see that a time study man is available when the job is ready.

Another large source of waiting time is the lack of constant supervision and sufficient foresight to have things ready on time or a little ahead of time. The foreman should know the schedule board's demands and be prepared for them. Lack of cooperation by the foreman with the planning department is a prolific source of loss of time due to schedule entanglements. If the foreman tries to swing the best jobs to his special favorites it often plays havoc with smooth running and waiting time will creep in.

Considerable time may be lost in some shops by failures in equipment. Transmission troubles, such as belts, gears, and chains, will occasionally cause delays unless the maintenance policy is organized to prevent it. Electric power failure is becoming less of a problem, but, where ordinary fuses are still used on lighting and power circuits, an occasional short overload will cause delays while fuses are replaced. Modern short-time, overloading devices can quickly be placed in service again by merely pushing a button.

Bearing and general lubrication troubles are generally due to a poor maintenance policy which can be corrected by adopting a modern system of preventive maintenance. (See Chapter XIV.)

Each cause of delay can be analyzed and all but a few can be eliminated by removing the cause.

Schedule Modifications. Modifications in the scheduled plan are necessary from time to time and usually the most common ones have

a procedure to follow. When a machine breaks down or work must stop on a partly finished lot for some other reason, the workman takes his uncompleted job ticket to the dispatcher and punches out. If the machine is down, the operator is either given a waiting-time ticket or is assigned to another job. If the current job is stopped because another order must be rushed through the machine, the rush job is punched in and the partly finished job ticket is placed in the second position on the planning board to be placed back on the machine when the rush job is finished.

When an order falls behind schedule it may be given preferential status over other orders of equal importance or, in serious cases, overtime may be used to speed up the completion of the lot and get the work station up to schedule again.

Behind-schedule orders or orders which have suddenly become "rush" sometimes can be split to get some of the parts through quicker than if the whole lot is run. The first split section may be given a letter suffix to the regular order number to keep its identity separate from the main order. A duplicate set of all forms necessary for the shop control must be made by hand for dispatching the special order. The first split section may be run like any regular order which is behind schedule as described in the previous paragraph. The second section of the split order should use the original prepared forms with the quantity reduced by the number run in the first split.

Chief Dispatcher. Where a plant uses a number of dispatch stations it usually is necessary to have a chief dispatcher to supervise the group. To be at all successful the dispatching system should be uniform over the plant. The chief dispatcher coordinates the various stations and reviews recommendation for changes; if acceptable, the changes are incorporated in all the stations. Thus it is possible to move dispatchers from one department to another with a minimum of new things to learn on the different stations. Generally the chief dispatcher works out of the central production control office.

The successful dispatcher should have several important traits but, most important, he must like to work with small integrated details. He must be an accurate clerk and above all a firm but cooperative person who does things by rule and yet who can induce workmen and foremen to follow these rules without making a show of authority. The dispatcher's station is no place for the careless, self-important, or procrastinating person.

Figure 4 shows in chart form ¹ the ordinary routine of a typical

¹ Adapted with changes and additions from *Principles of Industrial Management for Engineers*, L. P. Alford, Ronald Press, 1940, p. 295.

dispatcher's office. This routine will vary somewhat with the system used but in general this is about the type of control exercised in most plants.

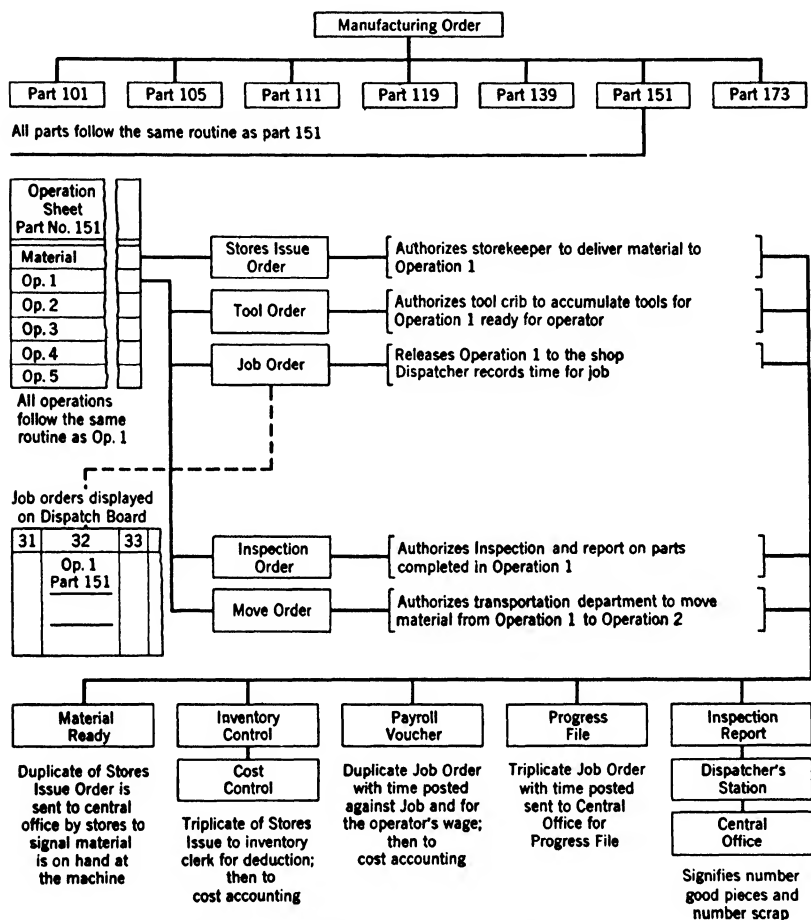


FIGURE 4. Ordinary dispatch office routine.

Effect of Production Control and Dispatching on Supervisors and Workmen. The old style foreman or those who have not had modern foreman training are often difficult to convince that production control will help them to become better foremen. The opposition is generally based on a fear of loss of power or prestige. The old line foreman of the last century did everything in the book. He hired men, fired them, and disciplined them. He was responsible for having the material on hand when the machine was set up; the tools for the job

also were his responsibility, and often he had to assist in getting them ready. He had to decide on the method to use, teach it to the workmen, set the speed of the machine, and inspect the product after it was finished. Especially, he was responsible for getting work out of the department on time, which meant he had to arrange his own schedules for all the operations in the department. Between times, he was supposed to keep the machinery in the department in first-class shape.

It is no wonder that Frederick W. Taylor criticized this type of factory organization. He said that, if a man were good enough to do a good job in all these duties, he was too good for an ordinary foreman's job.

From the time of Taylor's work the foremen have been losing prerogatives, but the foreman's job instead of becoming smaller has continued to grow in importance, prestige, and salary. The modern foreman is no longer an overworked combination detail clerk and stock chaser. He has time to cooperate with the planning department on methods, tooling, and other mechanical details of production. He is consulted by other foremen and the production office on production problems. In other words, the modern foreman is a man interested in producing goods by the best methods, and he thus becomes a leader of the men in his department. He provides the inspiration for his men to do a good job.

Not all men now on foremen's jobs are capable of this larger, broader vision which is so necessary in today's industry. They feel, if those things are done by others, that the foreman is a puppet with no duties and headed for oblivion. Some feel hurt but cover it up by sulking on the job, becoming rude, and not cooperating with the production control representatives.

Sometimes, where a particular foreman has a narrow point of view, it is cheaper and more satisfactory to find more suitable work for him where he can use his skills to better advantage. For those who have broadened their viewpoint, it should be pointed out that the foreman still is the boss of the department. He has a large voice in determining the machines to be used on the various products. He is directly responsible for the morale of his men and their production capacity. If anything is wrong with the planning of his department it is his responsibility to see that the planning procedure is corrected in consultation with the production control office.

General Rules for Foremen. The dispatcher's office must insist on a few rules to be observed by the foremen to protect the planning procedure. No foreman should give work to an operator without an order from the dispatcher. No foreman should order work moved

without a move order issued by the dispatcher with the single exception noted on page 534.

Any material which appears to be lost or forgotten in a department should be reported to the dispatcher. These few "must" rules do not mean that the foreman has nothing to say about their interpretation; but he must consult with the dispatcher first.

One of the important duties of the foreman is to check with the workman to compare the job order with the identification tags to see if they both are written for the same order. A double check here may save considerable lost time if a mistake is found after the setup has been partly completed.

The planned procedure for certain jobs is sometimes subject to criticism. The foreman and the workman should be encouraged to look for possible improvements in method and sequence of performing the operations. If worth-while improvements can be made the foreman should ask for an operation change to be used on the next scheduled run of the part.

The foreman should be responsible for recommending waiting-time requests. (See pages 542-543.) When an operator is on waiting time the foreman should correct the trouble as quickly as possible to reduce the lost time.

When material is inspected and found defective, the foreman should note if the operator's workmanship is faulty. Most shops pay only for good pieces produced; the number of defective pieces is reported to the dispatcher so that he can deduct them from the full lot count. If the parts can be saved by extra work, the foreman decides the operations that are necessary and notifies the dispatcher for later action. If the extra work costs more than some small maximum, say \$3, the foreman makes out an extra cost report which should be checked by the planning division for economic feasibility before the extra work is allowed.

Simple Clerical Duties for Foremen. The purely clerical functions of the modern foreman have been reduced to those which may directly affect his record of performance in his department. Waiting time is necessary, particularly when incentive systems are used in order to keep labor dissatisfaction down. However, the foreman should authorize the waiting time. Defective work is likewise the burden of the foreman since he and the operator are solely responsible. Planning mistakes increase production costs, and the foreman's record is partly based on reducing costs, so his own interests are served by asking for changes in method.

The foreman should report periodically to the dispatcher as certain conditions change in his department. The dispatcher is interested in (1) idle machines (not caused by no operator or no work), (2) absent workmen, (3) machines with no operator, (4) workmen with no work. These conditions are posted on the dispatch board and corrected by the dispatcher as soon as possible.

Effect of Production Control on Workmen. It is not unusual to have workmen offer passive resistance to any scheme of production control. Even simple schemes look complicated when viewed at a distance, and workmen seldom are in a position to have a chance to study the philosophy back of production control. Frequently workmen fear any new scheme because they feel it may be aimed, in some way, at their earning power.

Companies with good records of fair treatment of their employees usually have little trouble in convincing shop men that production control tends to increase wages. Others with less fortunate records may need to call in key workmen, shop committee men, or union leaders and actually show them how production control cuts down losses of all kinds. It should be shown to the workmen or their representatives how the common evil of waiting for various things, when on incentive, tends to decrease under production control; how tools and material are planned to be ready when a job is ready; how tools are pre-sharpened to save time on the machine and how good mechanics are saved the humiliation of turning trucker occasionally to get and deliver material around the shop. In other words, the mechanic's skill and good will are recognized as assets in production-controlled shops and they are valuable enough to be fostered and controlled for the benefit of both men and management.

General Routine for Workmen When Jobs Are Changed. Production control and dispatching does not change shop methods very much except that each step is clearly defined and followed closely. Any good shop whether it has a formal system of production control or not does about the same things as outlined below.

When a job is finished the workman returns any blueprints, the job order, and all tools which can be carried in one trip to the dispatch station. He turns in the job order and blueprints for the old job and receives the necessary orders and blueprints for the next job.

Assuming that the tool crib is close to the dispatch station, the workman takes his new order and the tools for the old job to the crib where the tool crib man has the tools accumulated for the next job. (Any large jigs, fixtures, or tools have been delivered by the move man directly to the work station.) After leaving the tools used on the last job the workman returns to the machine.

Some time before the last job was finished, the transportation department has delivered the material for the next job. The workman upon his return checks his new job order with the identification tag on the new material. Usually the foreman double checks this point to catch possible mistakes.

Either the machine has been set up previously by a setup man or the operator has to set up his own machine. In either case the first piece made from the new setup should be checked either by the foreman or a traveling inspector. If the machine is producing properly the order is run until finished. In some shops, the workmen are required to turn in job orders at the end of the day to the dispatcher whether the order is finished or not. Usually the number completed during the day is posted on the order for the information of the dispatcher. The next morning the workman punches in again on the order and proceeds as before.

When the job is finished the workman has the foreman sign the job order to signify to the dispatcher that all the work has been completed. The cycle is then repeated as outlined above.

Only a few general rules are necessary and these can be either posted on the dispatch station or emphasized to the workmen by both the foreman and dispatcher.

It is important for good dispatching that no new job is issued until all paper issued for the old job has been returned.

In any shop where it is impossible for everyone to know all the different parts which may be processed, it should be impressed on all persons that the identification tags on any job order are the only clues to the identity of the order. If a wired tag must be removed from a part to process it, the tag must be placed on one of the processed pieces to prevent the lot from losing its identity.

As a part of the benefits of production control to workmen (and likewise to cost of production after an analysis of lost time), the workmen should know that waiting time is paid for by making application to the foreman for a waiting-time form.

Summary. Dispatching and its method of control are necessarily a group of detailed clerical operations which are rather rigorously restricted by rules of performance. Unless this work is carefully done and the rules are followed the results will be no better than one could expect from a game of football or basketball when played without rigid rules.

The student of production control should try to absorb the philosophy of control rather than the detailed manipulation of a system of control. If the subject is approached from this viewpoint the details have a way of supplying themselves.

PROBLEMS AND QUESTIONS

1. How is dispatching done in a continuous industry?
2. What happens when dispatching becomes a rigid function?
3. Discuss the organization of the dispatcher's office and his relations with the foreman.
4. Discuss the dispatcher's responsibilities and name those which should be rigidly defined.
5. Under what conditions should material be moved without an order from the dispatcher?
6. How are tools for scheduled operations handled in a modern industry?
7. Discuss the general information which must be known about the material entering a department to be processed (not physical properties).
8. How can the foreman assist the dispatcher?
9. Draw up a dispatch board and devise a system for showing the status of the shop for which the board is designed.
10. Extend Problem 9 to include a system for dispatching jobs to the shop.
11. How would you reduce waiting time in a manufacturing plant?
12. What happens when waiting time is included in the allowance when a job is time studied?
13. Why did Taylor criticize the duties of the foreman in the industrial plants of 1900?
14. How are modern foremen different from the old-time foremen?
15. What are the duties of a modern foreman?
16. Discuss a method of determining how to coordinate amount of shop labor and shop load.
17. How would you convince a workman that production control would help him to be a better mechanic?
18. Would you be in favor of having the workmen follow the shop rules blindly or how would you do it in any other way?
19. How does the function of dispatching impress you as a means of aiding production control?

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CHAPTER XXV

MEASURES OF FACTORY PERFORMANCE

The successful management of modern industrial establishments requires the measurement and comparison of results accomplished in different periods. Also as production control and other factory management procedures are developed, their effect on the factory's operation and the product's cost should be measured periodically. It is important to determine if innovations in procedure have improved the performance of the factory's personnel, machines, and the use of capital. Comparisons of this nature must be made by studying the records of two comparable periods and expressing the results in common terms and identical units. Various cost ratios have been used as common bases for many comparisons but kilo-man-hours, volume of business, and total capital are also used quite often to express operating ratios.

The use of modern cost accounting and inventory control produces facts which are useful in making comparative reports of different periods. These reports may be used to show operating conditions of some of the functions in the factory. The proper use of such reports furnishes the executives with information which may be used to control the various functions and plant operations. The executive control under these conditions is more positive because the results of most shifts or changes can be studied soon after any changes are made.

Predetermining Performance. It has been stated that "until we measure we do not know," and this certainly holds true in management procedures. However, not all factory management values can be measured in advance of the decision by comparison with definite standards. Some activities of management must remain personal in character. That is, judgment will always be necessary for making many of the decisions in industry.

Nevertheless, though the use of judgment for making decisions can never be eliminated in certain aspects of management, progress toward prediction of results has been made in certain areas of plant management. It has become quite commonplace to predict and measure the performance of shop operations in practically all kinds of

industry. It is not so easy to predict the performance of most staff organizations, such as design, purchasing, production control, and other groups doing the thinking and planning for the factory's operation. In fact, the more a particular job or function utilizes the thinking and planning processes of people, the more difficult it becomes to predict the performance of the individual doing the work and the final results of his thinking processes.

Measuring Performance. However, though it may be particularly difficult to predict the final economic results of a proposed system of production control the results usually can be measured after the system has been in operation for some time. Likewise, the designer's calculation sheets and drafting boards do not always show progress from hour to hour nor sometimes from week to week, but over longer periods, his thoughtful deliberations, often featured by much pencil chewing, bring out ideas which culminate in a tentative design. If the tentative design appears to be promising, sample parts are made to develop further and to test the design. The real measure of the design department's effectiveness, however, comes from a long-range study of how well the designer's products have performed in the field and how well they have been accepted by the consumer.

To measure the performance of other portions of a factory organization, it is necessary to use data from many sources. These data in themselves are often a simple collection of facts which provide the basic information for making measurements of performance. Data from more than one report are combined to get certain useful ratios which develop as standards of comparison from one period to another.

Use of Performance Measures. The challenge to any executive is the difference between actual performance and the planned procedure. A successful administrator outlines his plans completely and definitely, but he constantly checks current performance and practice as compared to the theoretical plan. Unless he is so fortified, decisions cannot be sound except by pure chance.

The department executives should have definite objectives for their responsible activities. They should know when a job has been well done. The job standards should be written so that an employee can know when he has done a good job. There is a real chance to build morale in an organization by having attainable standards of performance for the employees to use as goals. If executives do not know what constitutes good performance, surely an employee cannot be expected to know.

Thus, though the number of hours of labor used per month in a certain department is interesting and helpful, these data are much

more useful if they are combined with other data which show the number of labor hours per unit of product, the number of labor hours per dollar value of product, or the labor cost per unit of product. Such ratios provide a standard of comparison which can be applied to the performance level of different periods to denote change.

Setting Up Standards for Measuring Performance. Before any standard of measurement can be set up it is necessary to know what is to be measured, to determine the unit of measurement, and to create or assert the standard by which these units of measurement are to be compared. It is sometimes difficult to know just what to measure when an executive's performance is to be measured. It would be interesting to know how the morale of the organization is developing under the executive's policies. What is the trend in quality of product and its effect on the amount of scrap? How has the unit cost been affected by recent decisions of the executive? Has production followed sales or has inventory turnover been increased? Each of these measures among others may be desirable at one time or another but the data, the units of measurement, and the standards for comparison mostly will be different.

Often a statistical approach has been used to discover ratios, percentages, and ratings which give significant values for various purposes. Such ratios as shown in Table 1 are examples which are of value for factory performance measurement. The ordinary balance sheet of an industrial concern contains data which can be used to express compound relationships of value.

TABLE 1

What Is to Be Measured	Unit of Measurement	Standard of Comparison
1. Turnover of fixed capital	dollars	$\frac{\text{Volume of business}}{\text{Total fixed capital}}$
2. Effective use of factory personnel	dollars	$\frac{\text{Volume of business}}{\text{Total factory payroll}}$
3. Turnover of inventory	dollars	$\frac{\text{Cost of yearly sales}}{\text{Average yearly inventory}}$
4. Operating efficiency	dollars	$\frac{\text{Operating profits}}{\text{Total capital}}$
5. Trend of operating results	dollars	$\frac{\text{Cost and expenses}}{\text{Volume of business}}$
6. Effectiveness of production planning	$\frac{\text{No. of jobs on time}}{\text{No. of jobs delivered}}$	% delivery promises kept

Brief Analysis of Measurement Standards. The volume of business per unit of fixed capital tended to go down in the United States during the long depression of the 1930's. This tendency may have been real but it also may have been due to a new scale of values brought about by the many bankruptcy procedures in the period and a corresponding adjustment in other companies to enable them to meet competition. The greater the volume of business which is actually produced by a plant's facilities (as measured in dollars of value), the less the overhead charges to be added to the cost of the product.

The ratio of volume of business to total fixed capital should not be taken too seriously by itself. If the measurement of turnover of fixed capital is used in conjunction with effective use of factory personnel, the combination gives a much better basis for study of results. If one of a group of plants which are manufacturing the same products has a low, fixed capital turnover, it may be using more labor per unit of product because of less efficient equipment. However, if both of these ratios are low, and if decent wages have been paid, the management has done a good job.

Inventory turnover is a ratio which shows how often the capital invested in the average yearly inventory is used during the year to provide the goods sold during the year. For the most effective use of this ratio the yearly average is usually used to smooth out sudden variations. Though a year's business is sometimes the basis for comparison, the year being compared is changed each month by adding the incoming month and removing the outgoing month. Thus, a running ratio figure is available which can show trends and developments more clearly. The larger this ratio becomes, the more effectively used is the capital invested in the inventory. The cost of yearly sales provides a better basis for calculating inventory turnover because the income from yearly sales is often beyond the control of factory executives and they should be judged by their actions in the factory and not by market variations.

The inventory turnover ratio is an important one because so many of management's triumphs and mistakes are quickly shown here. Any tendency to purchase more than necessary or to allow the accumulation of damaged or obsolete goods will quickly affect the inventory turnover adversely.

The operating efficiency is an over-all measurement of the management. The ratio of operating profits to total capital measures how well the management has been able to produce a profit with the plant's capital structure.

The trend of operating results as expressed in the ratio of cost and expenses to the volume of business will show when overhead charges are increasing per unit of product. This ratio should not arbitrarily be set at some fixed point for all conditions. As mechanization or improved methods are installed, overhead may increase, while the total factory unit cost may decrease. But for any given process or method where production machinery remains about the same, the trend of operating results should not be allowed to increase materially without inspection.

The effect of installing a system of controlling the flow of production can be partially measured by the study of a running report of the percentages of delivery promises kept. This percentage can vary from zero, under extremely bad conditions where no job during the month is delivered on time, to 100 per cent, where all jobs are delivered on or before the promised date. Some plants allow additional points where jobs are delivered before the promised date. This concept, however, may be subject to abuse by the control division which often sets the delivery date and thus can pad some percentages to increase the average performance.

Kilo-Man-Hour System. The kilo-man-hour method of analyzing industrial statistics has proved adaptable and useful since it was described in a series of papers¹ in 1928 and 1932. The kilo-man-hour system for evaluating industrial operating performance is based on the control of rates of expenditure for labor, material, and expense. The base or denominator of the various controlled rates or ratios is the man-hour. All industries have records of man-hours worked; consequently the kilo-man-hour ratios can be based on a standard unit for comparison. To reduce the numerical size of the figure in the denominator, the larger unit of 1,000 man-hours was used. Thus the kilo-man-hour system was named and since has become known as the KMH system of operating ratios.

The KMH unit was selected as the controlling factor in this series of ratios because (1) man-hours are established and available data in all industries; (2) man-hours are easy to handle in computation; and (3) man-hours have an important effect on industrial operation. By the use of the KMH system, a number of factors of industrial management may be measured to ascertain trends and positions of the

¹ "Measuring Operating Performance by the Kilo-Man-Hour," L. P. Alford and J. E. Hannum, *Mechanical Engineering*, Vol. 54, No. 12; "Applications of the KMH Method of Analyzing Manufacturing Operations," L. P. Alford and J. E. Hannum, *Transactions of the American Society of Mechanical Engineers*, Vol. 55, No. 5.

management procedures. The most important factors which should be measured and units used in the measuring ratios are shown in Table 2.

TABLE 2

FACTOR	RATIO AND UNITS
Costs	
Fuel and electric energy	
Manufacturing cost	
Materials cost	
Burden charges	<u>Dollars of Cost</u>
Prime cost	<u>KMH</u>
Salaries	
Supervision	
Value added by manufacture	
Wages	
Fixed capital investment	
Land	
Buildings	<u>Investment in Dollars</u>
Equipment	<u>KMH</u>
Primary power	<u>Kilowatts Used</u>
	<u>KMH</u>
Productivity	<u>Physical Volume of Products</u>
	<u>KMH</u>
Profit	
Manufacturing profit	<u>Dollars</u>
Selling profit	<u>KMH</u>
Net profit	
Selling price	<u>Dollars</u>
	<u>KMH</u>

Operating Ratios Are Not Universal in Character. In some instances there have been efforts to secure corresponding data from a large number of similar and dissimilar industries to compile a series of average ratios which can be used for comparison. Such data and the averages compiled from them should be used with care. Average values are often misleading if the data from which the averages were compiled have a wide spread.

The highly efficient power plant which uses a pound of coal or less per kilowatt-hour produced would get little benefit from the kilowatt-hour/pound of coal ratio as compiled from national data. The data collected from all parts of the United States would include the plants located near a cheap source of coal where combustion economy may

not be profitable as well as the small inefficient plants. Such data are of little value to the efficient plant.

If the management wants to compare the plant with others in its industry, ratios should be compiled from data gathered in plants of about the same size and character.

The wise manager will establish his own ratios from data collected from his own business and analyze them to find what must be done to make a profit. When budgetary control and production control are used to foster and promote good management, and when management will check and measure itself and its final operating results to improve such controls, we have scientific management in its best form.

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